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GEOLOGICAL MAGAZINE

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Zoned Hydrothermal Bodies in the Serpentinite Mass of Glen Urquhart (Inverness-shire).

By G. H. FRANCIS

ABSTRACT

Five bodies with either visible or inferred mineral zoning occur in the serpentinite mass in Glen Urquhart. Their mineralogy and petrology suggest a hydrothermal origin, and they are grouped with other hydrothermal injection phenomena in the glen thought go be phases of Older Granite activity. The two northern bodies seem clearly similar to simple vein deposits characterized by albitite without excess alumina (corundum). The origin of the remaining three bodies is discussed and the view that they too are deposits of albitite-type is favoured. They lack an exposed albitite zone, but this does not invalidate the comparison. Albitite deposits, it is suggested, originate where moving hydrothermal solutions from granites cut ultrabasic rocks. This origin for the veins is preferred to Larsen's (1928) suggestion that the hydrothermal veins represent late-stage sodic residual liquids left after the crystallization of most of the material of " ultrabasic magmas ".

INTRODUCTION

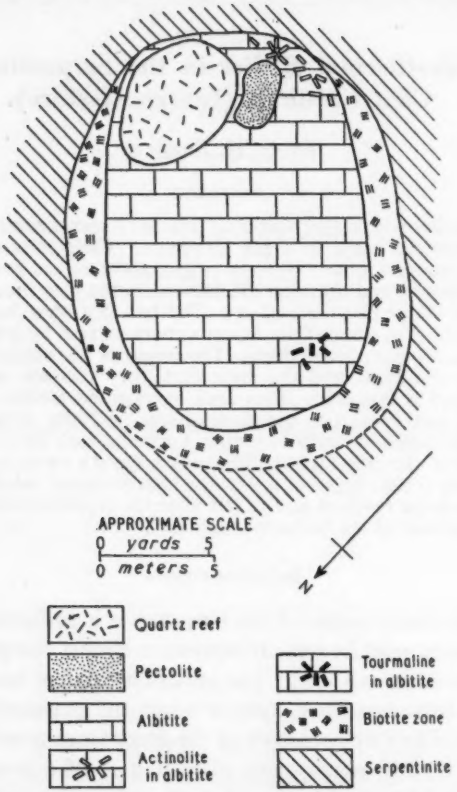
THE serpentinite mass in Glen Urquhart is a pod-shaped intrusion 0·89 square miles in area. It represents almost completely serpentinized olivinite and saxonite. The intrusion cuts the isoclinal folding of adjacent Moine limestone, kyanite-schist and psammitic gneiss, and is itself affected by metasomatism of the Older Granite period (Francis, 1955a). Part of this metasomatic alteration is of a permeating type producing amphibole-, chlorite-, and talc-rich serpentinites at or near the margins of the mass. These altered rocks grade off into normal serpentinite and are not in discrete bodies. They are described in the above paper.

There are in the serpentinite intrusion in addition, six masses of more discordant nature. One of these is a block of folded metasediment (kyanite-schist and impure limestone), the remaining five appear to be zoned hydrothermal bodies. They are the subject of this study. These zoned bodies are linked by similar minerals to pegmatites and metasomatic bodies in the surrounding Moine sediments. It seems reason-

able to group together all these metasomatic events as phases of the Older Granite (synorogenic, postkinematic) activity in Glen Urquhart.

Field Occurrence

The zoned bodies are shown on the map in the serpentinite paper (Francis, 1955a, fig. 1). They are here described from north to south.



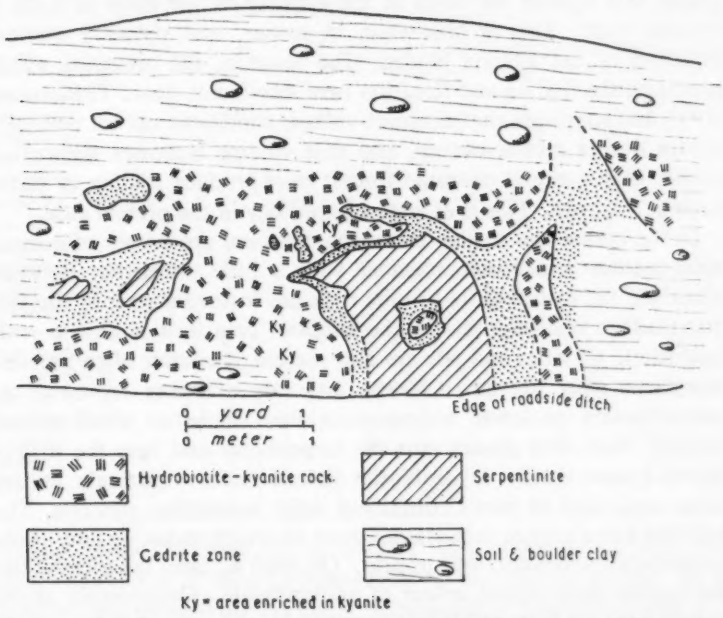
Text-fig. 1.—Sketch plan of the zoned hydrothermal body north-west of the summit of Beinn a' Ghairchin, Glen Urquhart.

The Beinn a' Ghairchin Zoned Body.—On the north-west slope of Beinn a' Ghairchin is a striking outcrop of white rock standing out from the buff-weathering serpentinite. It is a reef of oligoclase-rock (albitite) with white, altered feldspar crystals more than 15 cm. square. In one patch the albitite is replaced by greenish-white pectolite with a chalky-white, weathered crust. At the top and on the left side of the body is a reef of vein quartz. There is a small amount of pegmatitic

intergrowth at its junction with the feldspar. In the albitite near the top of the mass prisms of actinolite are common, and in the lower part of the albitite black tourmaline crystals occur. These are exactly similar to tourmalines in a granite pegmatite cutting Moine limestone in a quarry 900 m. to the north-east.

Marginally to the albitite there is a rim zone of biotite, or its altered equivalent, hydrobiotite with some chlorite. This zone does not extend round the top of the deposit and is badly exposed elsewhere. Mica-rich soil betrays its presence between the albitite and the serpentinite. A diagrammatic sketch of this body is shown in Text-fig. 1.

The Achnababan Zoned Body.—In drift 100 m. N.N.W. of Achnababan Croft are blocks of albitite, some containing actinolite identical with that in the Beinn a' Ghairchin body. Green prisms of apatite up



TEXT-FIG. 2.—Sketch of the zoned hydrothermal body in the roadside cutting at the fork of the road leading to Upper and Lower Gartally, Glen Urquhart.

to 2 cm. in length are present in the albitite. Some of the albitite blocks hold large plates of hydrobiotite up to 5 cm. in diameter, and this mineral is also abundant in the surrounding soil. These rocks and minerals are collected round rabbit burrows and seem clearly to indicate that a zoned hydrothermal body similar to that of Beinn a' Ghairchin lies under the drift here. Like the latter it is close to the western margin of the serpentinite mass.

The Milton Zoned Bodies.—Three zoned bodies have been found near the village of Milton. They differ from the preceding two in that no albitite is exposed.

(1) The first outcrops by the side of the road to Kiltarlity at its junction with the road to the Gartally farms. The rock here is very weathered and the exposure had to be re-excavated at each visit. It is so soft that it can be dug with the finger tips. A certain amount of fresh rock remains and the diagram (Text-fig. 2) represents the evidence pieced together in several visits. The bulk of the exposure is a very friable mass of lime-bearing hydrobiotite with kyanite. It is intensely folded and puckered. The hydrobiotite flakes are dark blue-green, weathering to bronze, and reach 5 mm. across. Between them white laths or blades of kyanite can be seen with the naked eye. In places this kyanite increases at the expense of the mica to form a kyanite rock. This is blue-white in colour, and shows a marked lineation of the kyanite blades. The sense of the pressures which produced the folding and lineation here seen is not clear. Poldervaart (1953) has suggested that constant-volume conditions do not normally obtain during metasomatism, and that volume increases themselves (rather than external orogenic forces) may produce folding in metasomatic deposits. This is at least a possibility in the present case.

In the centre and to the left of the exposure are bosses of normal mesh-texture serpentinite together with a little antigorite. Between these and the hydrobiotite-kyanite rock has formed a zone of roughly intermediate composition. In the simplest case it is a gedrite rock (gedritite). Chlorite and talc are also present, the latter often pseudomorphous after gedrite. Chlorite and talc probably represent recrystallization at lower temperatures than those at which gedrite formed. This zone grades into the serpentinite and into the hydrobiotite-kyanite rock. Hydrobiotite indeed occurs sparingly in this zone, and even in rocks containing relict serpentine minerals. The gedritite has a grey or iron-stained crust on which radiating fans of the amphibole up to 6 cm. long appear. On fresh surfaces the mineral has the typical clove-brown colour of anthophyllite. Occasionally in the gedrite zone are large crystals of hornblende, one such crystal measures $11 \times 7 \times 4$ cm. A small amount of actinolite has been found elsewhere in the zone. The exposure is cut by a few narrow veins of amorphous silica up to 2 cm. in width.

(2) About 15 m. along the Kiltarlity road from the above zoned body is a very small exposure of the gedrite zone which is represented by talc and chlorite. This may either be part of the same, or part of an adjacent zoned body.

(3) In a field overlooking the western end of Milton village is a small boss of hydrobiotite-kyanite rock. The crystallization here is coarser

than in the Gartally road fork exposure. Tourmaline prisms occur here.

Petrology

Vein Quartz and Albitite.—These appear to be hydrothermal deposits linked with similar veins and injections in adjacent Moine sediments. Identical tourmaline, for example, occurs in both. A small amount of pegmatitic intergrowth occurs, but it is not known why the minerals are otherwise dissociated. Larsen (1928, p. 412) records pure granular quartz at the centre of an albitite in Brinton's Quarry, West

Table I

Parageneses in the Zoned Hydrothermal Bodies

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
quartz	x																				
oligoclase		x	x	x	x	x	x														
muscovite			x																		
tourmaline				x																	x
actinolite					x									x							
pectolite					x	x	x	x								x					
calcite					x	x	x														
magnesite											x					x					
prehnite													x	x						x	x
hydrobiotite							x		x			x	x	x		x	x	x		x	x
chlorite						x			x	x	x	x		x	x	x	x				
talc										x	x	x		x	x	x	x				
serpentine minerals										x		x					x				
gedrite									x	x	x	x	x								
hornblende													x								
kyanite																			x	x	x
rutile																			x	x	x
apatite							x														

Chester, Penn. Serpentinite in contact with albitite, and near the quartz at the top of the exposure shows no regenerated olivine. In a hydrous environment olivine might be expected to form about 400° C., and all the serpentine should have been changed to olivine above 500° C. (Bowen and Tuttle, 1949). Examples of regenerated olivine are given by Durrell (1940), MacDonald (1942) and Leech (1953). Liquid oligoclase probably could not exist below 1300° C., and liquid silica below 1710° C. Being separate masses there is no question of an eutectic lowering of melting points of the quartz and feldspar. It seems likely therefore that they were formed hydrothermally at temperatures at or below 400° C.

In thin section the vein quartz is " hairy " with fine inclusions, it has

TABLE II

Analyses of Rocks from Zoned Hydrothermal Bodies in Glen Urquhart and North East Transvaal

	1	2	3	A	B	C
SiO_2	34·23	40·93	34·46	39·60	30·25	38·72
TiO_2	1·70	0·65	3·60	—	0·10	—
Al_2O_3	31·60	26·27	58·41	52·60	57·90	52·90
Fe_2O_3	1·98	2·33	0·84	—	2·05	trace
FeO	3·36	9·85	0·09	—	1·25	
MnO	0·05	0·10	nil	—	—	—
MgO	5·72	7·44	nil	0·32	0·10	5·16
CaO	6·79	5·20	1 56	1·50	2·10	—
Na_2O	0·23	0·84	nil	5·70	3·00	1·45
K_2O	2·05	0·27	0·23	—	2·10	—
P_2O_5	nil	0·09	nil	—	trace	—
H_2O^+	7·75	5·86	1·09	0·06	1·05	1·10
H_2O^-	4·46	0·48	0·06			
	99·92	100·31	100·34	—	99·90	99·33
Sp. Gr.	2·57	3·17	3·49	—	3·22	—

1. Hydrobiotite-kyanite rock, Gartally road fork, Glen Urquhart, H.C. No. 76, 303.[1] Analyst, G.H.F.
2. Gedritite, same locality, H.C. No. 76, 306. Analyst, G.H.F.
3. Kyanite rock same locality. H.C. No. 76,304. Analyst, G.H.F.

A. Calculated chemical composition of plumasite, Turkaspost, N.E. Transvaal. A. L. Hall (1920), p. 132, Feldspar, Analyst, C. C. Gardthausen. (See explanation in text.)

B. Corundum reef, Blydschap, N.E. Transvaal. A. L. Hall (1920, p. 80). Analyst, Dr. McRae.

C. Corundum rich rock, Malelane, N.E. Transvaal. A. L. Hall (1920, p. 125). Analyst, C. C. Gardthausen.

TABLE III

Trace Elements in the Analysed Glen Urquhart Rocks

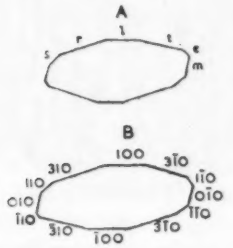
(parts per million)

	1	2	3
Li	30	100	45
Rb	20	*	*
Cs	*	*	*
Sr	80	20	1,500
Ba	250	100	150
Sc	*	15	*
Ga	15	15	50
Yt	*	10	*
In	*	*	*
La	*	—	*
Tl	*	*	*
Zr	1,000	300	1,500
Sn	*	*	*
Pb	*	*	*
V	70	150	100
Cr	50	150	250
Mo	*	*	*
Co	15	20	*
Ni	50	30	30

1, 2, and 3 correspond to 1, 2, and 3 of Table II. An asterisk means probably present, but below the limits of quantitative determination.

[1] Harker Collection, Department of Mineralogy and Petrology, Cambridge University.

sutured margins and very undulose, strained extinction. The individual crystals reach 1 cm. across. The oligoclase shows an extremely patchy growth, with much evidence of replacement. Pericline and albite twinning occur. Compositions range from An_{16} to An_{28} in a single crystal. The calcic material predominates. Sericitic alteration is very common. Similar oligoclase rocks occur in injected kyanite-schist adjacent to the serpentinite. Pectolite replaces the Beinn a' Ghairchin oligoclase along cracks and cleavages. It belongs to a small-scale, and late lime-rich phase of the metasomatism. Hydrothermal alteration in the surrounding sediments is all lime-bearing and it seems clear that the solutions have picked up lime from the adjacent Moine marbles. A late lime-bearing metasomatism, forming prehnite in an albitite, is described by Watson (1953). Pectolite is also common in marginal injected sediments, as is actinolite.



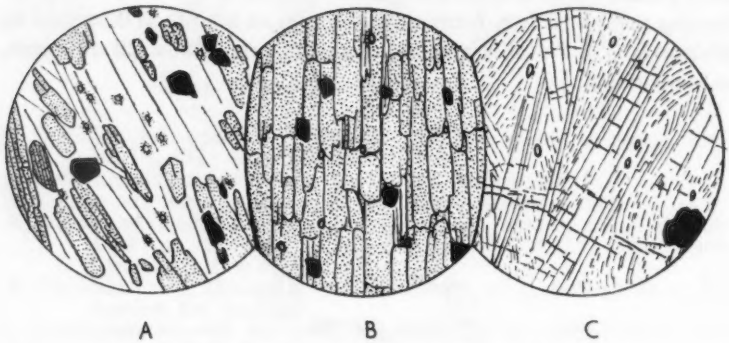
TEXT-FIG. 3.—(A) " Xantholite ", a cross section of the prism zone after the sketch in Heddle (1879).
(B) Prism zone of kyanite drawn from the measurements of Barić (1940).

Biotite Zone of the Two Northern Bodies.—The mica of this zone at Beinn a' Ghairchin is blue-green, has no exfoliation, and gives the X-ray pattern of biotite. Its golden yellow weathered product has limited exfoliation and the X-ray pattern of a hydrobiotite. At Achnababan the coarse mica flakes are all hydrobiotite with an exfoliation to *ca.* 5× the original thickness. These micas will be described in a paper on the vermiculitic minerals of Glen Urquhart.

Hydrobiotite-kyanite Rock.—The former mineral predominates in this rock. It is lime-rich and possesses Ca^{++} exchangeable ions in the interlayer positions. X-ray patterns suggest that some margarite layers are present. Prehnite grows in the cleavages of this mica. Hydrothermal alteration in kyanite-schist marginal to the serpentinite has produced hydrobiotite with prehnite in its cleavages, and in the surrounding groundmass. This again shows the lime-bearing nature of the metasomatism within and without the serpentinite. Kyanite is present in laths with much less cleavage than usual. This must be the result of being embedded in the soft mica. Rutile is abundant in small red grains

sometimes with (101) twin planes. These must be the small pink " garnets " recorded by Heddle (1879) at this locality. Zircon is also abundant, forming strong pleochroic halos in the hydrobiotite. The rock is shown in thin section in Text-fig. 4A, and its chemical and trace element composition appears in Table II, 1, and III, 1. A volume mode of this rock estimated on a point counter gave : hydrobiotite (with prehnite), 75·52 per cent ; kyanite, 22·30 per cent ; rutile, 0·88 per cent ; zircon, 1·29 per cent. Tourmaline occurs in the Milton exposure.

Kyanite Rock.—Small areas not in contact with the gedritite show a steady increase in kyanite and decrease in hydrobiotite ending in a



TEXT-FIG. 4.—Thin sections of rocks from the Gartally road fork exposure, Glen Urquhart. All are in plane light, with magnification about 12×.
(A) Hydrobiotite-kyanite rock.
(B) Kyanite rock.
(C) Gedritite.
Key to the ornament: stippled = kyanite; plain with cleavage = hydrobiotite ; black = rutile ; small oval circles (with pleochroic halos in hydrobiotite) = zircon ; close prismatic cleavage and basal parting = gedrite.

kyanite rock. This contains the rutile, zircon, and hydrobiotite in minor amount. Prehnite appears to have persisted more than vermiculite, and occasionally can be seen between the kyanite blades. It probably accounts for the proportionately high strontium amongst the trace elements. Heddle (1879) recorded a possible new mineral " xantholite ", a variety of staurolite, from this locality. No staurolite has been found in numerous slides cut from these rocks. Heddle's analysis could be interpreted as kyanite contaminated by hydrobiotite. Moreover, the freehand sketch of a prism zone given by Heddle (Text-fig. 3A) can be closely matched by a prism zone constructed from the careful measurements on kyanite by Barić (1940), (Text-fig. 3B). No kyanite appears to persist to the edge of the gedrite zone, a thin rim of hydrobiotite intervenes, consequently no kyanite-gedrite para-

genesis (Tilley, 1939) occurs. A volume mode of this rock gave: hydrobiotite (with prehnite), 0·34 per cent; kyanite, 93·24 per cent; rutile, 4·48 per cent; zircon, 1·94 per cent. A thin section is shown in Text-fig. 4B and the chemical and trace-element compositions of the rock are given in Tables II, 3, and III, 3.

Gedrite Zone.—Rutile and zircon occur in the gedrite. Rutile is sometimes clustered in veins, showing that it is undergoing transfer and is not a relict mineral. In the sediments there is more rutile the closer one approaches to the serpentinite. The rock is otherwise almost pure gedrite (Text-fig. 4C). Where altered or replaced it appears as a confused aggregate of talc, often pesudomorphous after gedrite, chlorite, prehnite, pectolite, hydrobiotite, magnesite, and serpentine minerals. The large hornblendes of this zone have the following pleochroic scheme: α = pale straw; β: straw; γ: leaf green, and $N_\beta = 1{\cdot}643 \pm{\cdot}002$ (sodium light). The pale actinolitic amphibole has: α: colourless; β: pale olive; γ: pale grass green. $N_\beta = 1{\cdot}634 \pm {\cdot}002$ (sodium light), and the extinction $\gamma \wedge c$ on (010) is 22°. Chemical and trace element analyses of the gedritite are given in Tables II, 2, and III, 2. The gedrite is notably rich in alumina and in water (Francis, 1955b), no doubt because it lies between the aluminous hydrobiotite-kyanite rock and the hydrous serpentinite. The chemical grading, mineral zoning, and pseudomorphous replacement in these bodies offer a clear case for their hydrothermal origin. Parageneses observed in the zoned bodies are given in Table I.

Discussion

Nature and Origin of Albitites and Related Rocks

An obvious parallel with the Glen Urquhart zoned hydrothermal bodies is provided by the albitite deposits. The salient features of these deposits (particularly those of the eastern U.S.) have been lucidly treated by Larsen (1928). References to other similar deposits are given by Larsen, notably A. L. Hall's description (1920) of the north-east Transvaal corundum fields, and Du Toit's work (1918) on rocks from Natal. Pabst (1942) describes similar zoned associations at Humphreys, California. Varley (1952) gives notes and references to a large number of similar deposits throughout the world. The latter work lists commercially valuable occurrences of vermiculite, which almost all occur in deposits of albitite type.

Some of the features of these deposits are now summarized:

1. The deposits all occur where granitic rock has formed in the vicinity of pre-existing ultrabasic rock (pyroxenite, hornblendite, dunite, serpentinite, etc.), and where veins from the former have entered the latter rocks.

2. Reactions between the vein material and the wall rock have produced zoned bodies, often with bilateral symmetry. Minerals of the marginal zones (e.g. talc, vermiculite, anthophyllite) are simply of a composition intermediate between the granitic veins and the wall rock. In some, but not all cases, another group of minerals (e.g. corundum and kyanite) also forms. These indicate the generation of an excess of alumina during the alterations.

3. There is great variety in the shape and nature of the bodies. They may be straight-walled and dyke-like, polygonal or tortuous in outcrop. The zones have very varied distribution. Individual zones can either predominate over all others or be entirely absent. Perhaps the commonest case is a wide central outcrop of albitite, with narrow margins of biotite or vermiculite. Quartz or pegmatite may be present at the centre of these veins. This is the position at Beinn a' Ghairchin, and probably in the concealed body at Achnababan, Glen Urquhart. In other bodies the excess of alumina appears as corundum crystals, which when set in the albitite form the rock plumasite. Sometimes quartz-feldspar pegmatite may occupy the centre of a vein, albitite flanks it, plumasite flanks the albitite, and the margins are composed of vermiculite. In at least one case pegmatite flanks plumasite (Stukfontein, N.E. Transvaal, Hall, loc. cit., p. 105). In no case are quartz and corundum found together. They are always separated by a zone of albitite.

4. Quartz and plagioclase are not always present. Ross, Shannon, and Gonyer (1928, p. 532) describe an area of veins in dunite near Webster, N.C. where the deposits grade upwards from thin veins (3–4 cm.) with anthophyllite + talc, or anthophyllite + tremolite + talc. Slightly larger ones have an inner core of vermiculite, with a transition zone of complex intergrowth of vermiculite with anthophyllite, tremolite, and chlorite. Only the largest veins (25–30 cm.), and these rarely, contain a discontinuous central zone of coarse albite. Larsen (1928, pp. 414–15) describing a Pennsylvania occurrence writes:

> " In many of the veins albite is lacking and this is especially well shown in Brinton's Quarry where a network of veins with centres of vermiculite and outer layers of anthophyllite and talc cut the serpentine, whereas albite is found only locally where the veins are unusually wide. In general as the veins become narrower first the albitite pinches out, then the mica layer, and finally the amphibole."

5. In rocks in which excess alumina has been fixed kyanite apparently can take the place of corundum + feldspar, when alkalis are deficient. The analysis of kyanite rock from Glen Urquhart (Table II, 3) compares quite closely with three plumasitic rocks described by Hall (loc. cit.). The Turkaspost plumasite analysis (Table II-A) is

calculated from the analysis of Turkaspost feldspar and the stated composition of the plumasite (60 per cent feldspar, 40 per cent corundum). II-B is normal plumasite. II-C is said to be corundum-rich, but the analysis, the photomicrograph, and analogous rock near by (at Mashishimala) all suggest the presence of kyanite and some mica (Hall, loc. cit., p. 125). Kyanite in a plumasitic environment has been recorded by Hall, Brandt (1940), and Van Eeden (in discussion on Brandt, 1940).

6. Larsen (1928) has pointed out that the previously held view that albitite-plumasite bodies form from granite pegmatite magmas in situ is untenable. The desilication of the magmas implied by the anthophyllite, talc, and vermculite marginal zones would be insufficient to produce a residual liquid which could precipitate corundum, moreover there is no simple relation between the width of plumasite and the width of the marginal zones. The conclusion is that the bodies formed from *moving* solutions under sub-magmatic (hydrothermal) conditions. The absence of regenerated olivine in the wall rock at Glen Urquhart supports the theory of a lower temperature origin for the bodies. Larsen considered that " the solutions emanated from the ultrabasic " (i.e. the wall rock) " or a related deep-seated magma", and states that this theory " accounts for all the phenomena . . . with the exception of the observations that dikes remain pegmatitic in granulite and are changed to plumasite in serpentine " (loc. cit., pp. 431–2).

It is now generally held that ultrabasic (e.g. dunite) magmas do not exist in the upper crust (Bowen and Tuttle, 1949), and that dunites represent aggregates of olivine crystals either gathered by crystal settling from basaltic magma or, in the case of the " alpine " type forcibly intruded as a mush of crystals, with perhaps intercrystal films of water vapour. In neither case can there be late-stage solutions from " ultrabasic magma". Since 1928 it has perhaps become easier to postulate granitic material in a submagmatic (hydrothermal) state. It appears that a derivation of the albitite-plumasite veins from such a source will meet all the requirements of field evidence (see also Du Toit, 1928).

Nature and Origin of the Glen Urquhart Zoned Hydrothermal Bodies.

As said in Section 2 above, the two northern zoned bodies at Glen Urquhart seem to correspond to the simple type of albitite in which no excess alumina has been precipitated.

The remaining three zoned bodies (typified by the Gartally road fork body) might represent (1) much transformed inclusions of kyanite-schist country rock which have lain in the path of hydrothermal solutions, or (2) the basic (marginal) assemblages of typical albitite-type bodies.

The presence of kyanite in sediments adjacent to the serpentinite, and in one inclusion within it appears to favour origin (1). The kyanite in the zoned bodies would thus be relict kyanite in otherwise completely transformed wall rock, and all the kyanite in Glen Urquhart would have the same origin. Moreover, original biotite in hydrothermally altered kyanite-schist at one point adjacent to the serpentinite is represented by hydrobiotite. However, in this same hydrothermal alteration (which like that of the zoned bodies carries some lime) kyanite has been converted to muscovite and prehnite in all rocks containing hydrobiotite. It therefore seems unlikely that the kyanite in the zoned bodies represents a resistant relict mineral in otherwise completely transformed wall rock. No intermediate stages in this quite drastic transformation are preserved.

For origin (2) it can be said that:

1. All the mineral zones of these bodies have been found in albitite-plumasite veins, zoned in the same order. No appeal to an inclusion of kyanite-schist as host rock seems necessary. In particular a comparison can be drawn between veins in Pennsylvania and in the Transvaal:

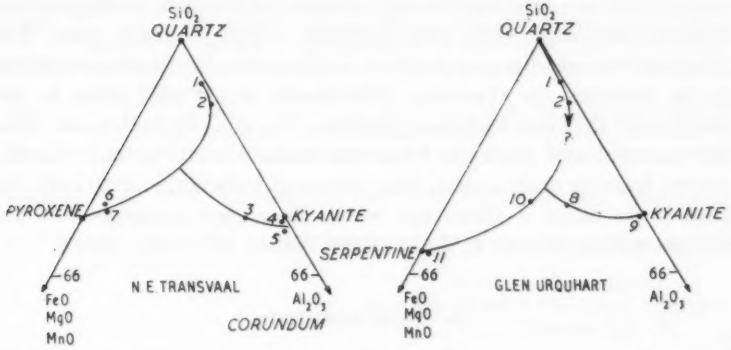
Brinton's Quarry, Penn. *Zones*	*Glen Urquhart* *Zones*
1. Serpentinite.	1. Serpentinite.
2. Anthophyllite, talc, chlorite, and serpentine.	2 + 3. Gedrite (anthophyllite), locally replaced by talc and chlorite, vermiculite and serpentine are present.
3. Talc vermiculite and anthophyllite.	
4. Coarse vermiculite with some feldspar and chlorite.	4. Thin zone of kyanite-free hydrobiotite (vermiculite).
5. Albitite with large vermiculite plates.	5. Hydrobiotite-kyanite rock.
	6. Kyanite rock.

As can be seen the zoning is very similar as far as zone 3 in the Pennsylvania body (Larsen, loc. cit., p. 410) and the Glen Urquhart body. From zone 4 towards the central zone they begin to diverge, the first towards an albitite without excess alumina (corundum), and the second towards excess alumina with deficient alkalis (kyanite). The rocks of the central zones at Malelane and Mashishimala, N.E. Transvaal (Hall, loc. cit., pp. 124–8) provide a rough parallel with the Glen Urquhart hydrobiotite-kyanite and kyanite rocks. The former are corundum-kyanite-plagioclase-biotite rocks, containing more soda than the Glen Urquhart central zones. Their chemistry is otherwise similar.

2. Although poor exposure may have hidden albitite in the Glen Urquhart bodies it may not be present, and its absence does not affect

the comparison since several albite-free bodies have already been described.

3. The accessory minerals at Glen Urquhart, such as apatite, zircon and particularly tourmaline (Larsen, loc. cit.) and rutile (Hall, loc. cit.) have all been found in rocks of albitite-type.



TEXT-FIG. 5.—Plots of zoned hydrothermal bodies from N.E. Transvaal, (analyses in Hall, 1920) and from Glen Urquhart. Apices are molecular proportions of SiO_2, Al_2O_3, and FeO + MgO + MnO recalculated to 100 per cent. Explanation in text.

The chemical similarity between the Glen Urquhart zoned bodies and typical rocks of albitite-type from N.E. Transvaal is approximately shown in Text-fig. 5. The apices of the triangles are molecular proportions of SiO_2 ; Al_2O_3 and FeO + MgO + MnO.

The following are the plotted points.

1. Plot of 33 per cent quartz, 66 per cent average feldspar (No. 2), an assumed composition of the simple pegmatites of N.E. Transvaal (Hall, loc. cit., p. 42).

2. Average analysis of three plagioclases from albitites, N.E. Transvaal (Hall, loc. cit., p. 132).

3. Corundum-kyanite rock, Malelane, N.E. Transvaal (Table II-C of this paper).

4. Calculated composition of plumasite, Turkaspost, N.E. Transvaal (Table II-A of this paper).

5. Corundum reef, Blydschap, N.E. Transvaal (Table II-B of this paper).

6. Pyroxene-hornblende rock, Styldrift, N.E. Transvaal (Hall, loc. cit., p. 47).

7. Pyroxene-hornblende rock, Pietersburg, N.E. Transvaal (Hall, loc. cit., p. 47).

8. Hydrobiotite-kyanite rock, Gartally road fork, Glen Urquhart (Table II-1 of this paper).

9. Kyanite rock, same locality as 8 (Table II-3 of this paper).
10. Gedritite, same locality as 8 (Table II-2 of this paper).
11. Serpentinite, Glen Urquhart (Francis, 1955a).

Pyroxenite is the wall rock in most of the Transvaal bodies. It is serpentinite at Glen Urquhart. The similar formation of excess alumina rocks in the two localities (as well as zones intermediate in composition between pegmatite veins and ultrabasic walls) is clearly seen. The Transvaal vermiculite and the Beinn a' Ghairchin biotite are not plotted as no analyses are available. Vermiculite would plot close to the position of the Glen Urquhart gedritite (No. 10). Pegmatite and albitite are re-plotted from the Transvaal to the Glen Urquhart triangle, where, together with quartz, they represent sufficiently accurately the core of the Beinn a' Ghairchin body. They are not exposed and are not necessarily present in the southern bodies, as already stated.

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A *Myalina* fauna from the Namurian of North Ayrshire.

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Abstract

The Maich Shell Bed of the Limestone Coal Group of the Carboniferous of North Ayrshire bears a dominantly lamellibranch fauna but includes the brachiopod *Lingula squamiformis* Phillips. The majority of the shells are here referred to *Myalina magna* (Hind). An emended description of this species is given, and its affinities with certain species of *Myalina* and *Naiadites* from the Namurian and Lower Carboniferous are discussed. The variation in the *Myalina* community and the distortion due to crushing are examined, and an attempt made to distinguish between them.

Introduction

In North Ayrshire, about 30 feet below the Dalry Blackband Ironstone, in the Limestone Coal Group of Namurian age (*vide* Currie, 1954, p. 532), there occurs a shell bed. The term Maich Shell Bed was first used by Richey and others (1930, p. 173) who gave a list of the fauna. The Maich Shell Bed is well developed in Maich Water, outcropping 1 mile upstream from Kerse Bridge (1 mile north of Kilbirnie), and it has also been found 1 mile south-south-east of Beith in the railway cutting north of Ward Farm, and in the railway cutting near the disused Brackenhills Station on the Beith branch line. Neither of these last two exposures is good, but sufficient shells were obtained from the latter to establish the similarity of the fauna to that of the Maich Water exposure. This paper deals with a single community, that from Maich Water.

The Maich Shell Bed marks the initiation of a cycle of sedimentation in a limited area of North Ayrshire. A 2 ft. bed of shale with large *Lingula* is followed some 3 feet higher by the Maich Shell Bed, 1 ft. 1½ in. thick. This bed is crowded with calcite-shelled fossils the light colour of which contrasts with the dark matrix. The detailed succession is:—

	ft.	*in.*	
Maich Shell Bed, 1 ft. 1½ in.		3	Ironstone with lamellibranchs.
		1½	Ironstone, barren.
		9	Shaly mudstone with lamellibranchs and *Lingula*.
	3	4	Shale w. thin ironstones (unfossiliferous).
	2	0	Shales with few large *Lingula*.

The fauna of the Maich Shell Bed is not very varied and comprises chiefly lamellibranchs. The shells were mostly referred to *Myalina* by the late G. W. Lee (in Richey, 1930, p. 173), and *Lingula squamiformis* Phillips is abundant. In spite of extensive collecting no other marine lamellibranchs were found by the author, but Macgregor (1930,

p. 526) lists *Edmondia* and two species of *Aviculopecten* in addition. These have been examined in the collection of the Geological Survey, Edinburgh; and, in the collection of the Hunterian Museum, Glasgow, among material collected by Drs. Currie and Weir, *Pterinopecten* has been noted. The presence of marine lamellibranchs other than *Myalina* is therefore well established, but it may be supposed that their occurrence is rare and insufficient material is available to determine their precise disposition in the shell bed relative to *Myalina*. Two fish scales have been found and two specimens of *Carbonicola* sp., suggesting that the material may have drifted into situ, further indicated by the fragmentary condition of the shells. Hence the precise conditions of sedimentation cannot be deduced from the fauna.

The Myalina Community

The myaliniform shells were first referred to the genus *Myalina* by G. W. Lee (in Macgregor, loc. cit.). That some doubt had existed as to the identity of the shells is expressed by Lee in the description of the fauna: " . . . a marine assemblage, and does not include *Naiadites* as formerly supposed. The prevalent shell is a thick-walled *Myalina* specifically indeterminable on account of the distorted condition of the specimens " (also see Richey and others, 1925, p. 23). The author originally believed these shells to be referable to *N. crassa* (Bennison, 1954, p. 53), but re-examination of the material has shown this identification to be erroneous.

Weir and Leitch (1942, p. 20) record *N.* cf. *tumidus* from a somewhat higher horizon (the blaes above the Lower Garscadden Blackband) in the Glasgow area and in a boring at Motherwell Bridge. Leitch (1941, pp. 216, 217, fig. 7) describes and figures *N. tumidus* from the Dalry Blackband Ironstone of Dalry, some 30 feet higher in the succession than the position of the Maich Shell Bed. The similarity of this material to the Maich Shell Bed *Myalina* is discussed later

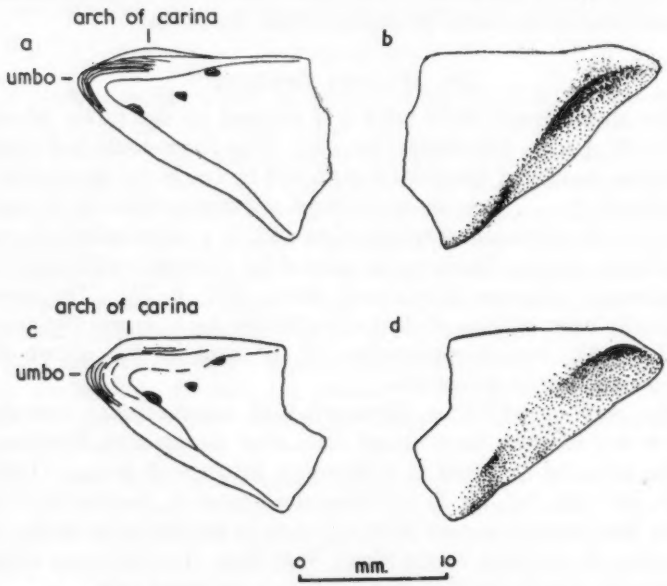
These myaliniform shells from the Maich Shell Bed are referable to the genus *Myalina* rather than to *Naiadites*. The basis for maintaining the identity of these two closely related genera was laid down by de Koninck (1842, p. 125 et. seq.). The principal difference of external morphology between them is that in *Naiadites* the umbo is never terminal. There is, of course, also difference of environment, although Hind (1893, p. 514) has shown that, at least in the case of *Naiadites crassa*, this cannot by itself be taken as diagnostic. Newell contrasted the musculature of the respective type species (1940, pp. 291, 294), and established slight differences of shell structure (1942, pp. 45, 71).

The following characters observed in the shells under discussion

illustrate how closely they resemble certain *Naiadites*, but the first confirms their identity as *Myalina*:—

(i) The umbones are terminal. Growth lines which would define precisely the tip of the umbo are seldom seen. This is often difficult to determine, especially as the carina may curve upwards from the umbo above the hinge-line, and the arch of the carina may be mistaken for the umbo. The terminal position of the latter implies an entirely opisthodetic condition of the ligament; in *Naiadites* the ligament is amphidetic.

(ii) The hinge is edentulous, the usual condition in *Naiadites*.



TEXT-FIG. 1.—The anterior ends of two specimens of *Myalina magna* (Hind) from the Maich Shell Bed, Maich Water, to show musculature in relation to the carinal feature. Muscle pits in black. (Hunterian Mus. reg. nos. a and b: S. 6082; c and d: S. 6083.)

A rudimentary tooth articulating with a primitive dental socket is commonly present in *Myalina*, but the hinge may be edentulous as in this case.

(iii) The shells lack a rostral plate. This feature, present in some *Myalina*, is not a diagnostic generic character. Although the presence of an anterior septum was included in de Koninck's original diagnosis, Newell (1940, p. 287) has shown that such a feature is not present in the subsequently chosen genotype.

(iv) The ratio of H/L is lower than that found in many later *Myalina*, but compares with *Naiadites*. It is comparable with that of the Mississippian *Myalina* figured by Newell (1942, fig. 12), in which length is greater than height, reflecting a primitive condition.

(v) In a very few specimens three muscle pits may be seen near to the anterior end. They lie in an oblique postero-dorsal—antero-ventral line (Text-fig. 1) and the anterior adductor scar, though small, is the largest of the three. Dr. J. Weir has drawn my attention to the fact that the musculature is not diagnostic of *Myalina* in which the central pit, that of the inferior pedal muscle, is the largest of the three anterior pits, but resembles more closely the musculature of *Naiadites*, since the anterior adductor is the largest. The three muscle pits are seen to lie in a nearly straight line. This line has different inclinations in Text-fig. 1*a* and 1*c*, and exterior views (Text-fig. 1*b*, 1*d*) of these specimens show that the inclination is related to differences in the proximal development of the respective carinae.

Variation in the Community.

The community appears to show great variation, but close examination shows that it is largely attributable to (1) distortion of the shells resulting from crushing and (2) the incompleteness of the shells; the posterior-dorsal area is often missing.

(1) *Apparent Variability due to Distortion.*

Shells lying parallel to the bedding planes appear to be least distorted, although the degree of flattening of the carina cannot be estimated. Even shells which lie at a quite small angle (up to 10°) to the bedding are considerably distorted; the effect in shells tilted so that the hinge-line is lower than the ventral margin, is to accentuate the carina and make it more sharply ridged. In shells tilted in the opposite direction, crushing tends to obliterate the carina by " spreading it out ". A very few shells become embedded at a large angle to the bedding planes. In these the crushing appreciably affects shell shape, as well as the form of the carina, and the ventral margin may be concave so that the shell assumes a kidney shape. Possibly a byssal sinus was present in these shells.

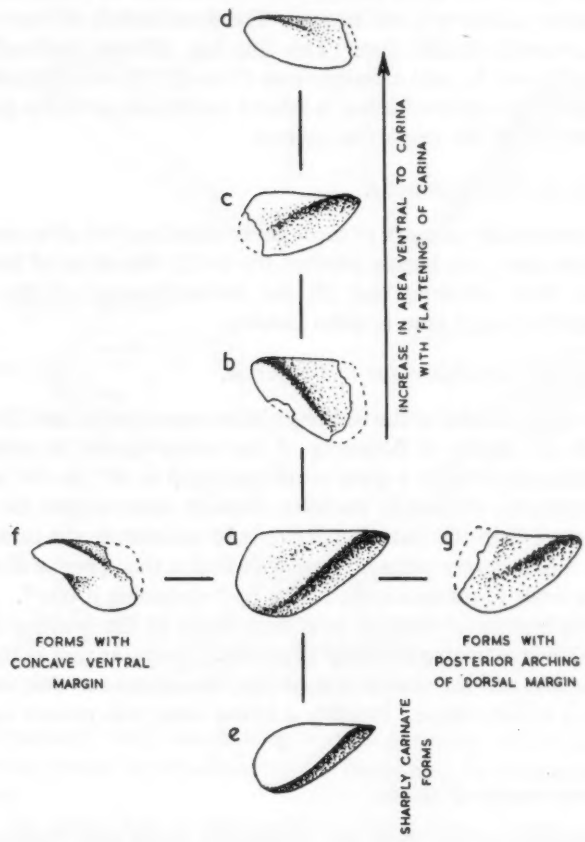
(2) *Incompleteness of Shells.*

The majority of the shells are incomplete, some even fragmentary, due probably to wave action or subsequent crushing. In a large number of shells the postero-dorsal area has been lost—or is hidden—and the shells simulate *Carbonicola* in outline (noted by Leitch (1941, p. 218)). Hence the diagnostic measurements and ratios cannot be determined.

(3) *Inherent Variation.*

Inherent variation occurs and is chiefly due to combinations of the following factors:—

(i) The ventral margin may vary from a gently rounded convex curve to a sigmoidal curve.
(ii) The dorsal margin may be arched posteriorly.
(iii) The carinal feature shows variation in position, in degree of arching, and it may be prominent or flattened.



TEXT-FIG. 2.—Variation in *Myalina magna* (Hind) from the Maich Shell Bed, Maich Water. About half natural size. (Hunterian Mus. reg. nos. a: S. 6080; b: S. 6081, other specimens in author's collection.)

All these characters, but in particular the last, are susceptible to modification by crushing. Since the amount of distortion due to crushing appears to be minimized in shells lying with the plane of the valves parallel to the bedding planes, variation in the community may be studied by considering only these shells. Selected variants representing series of change from the norm are shown in Text-fig. 2. Though not completely eliminated, the effects of distortion have been minimized by choice of specimens. Since the bulk of the shells lie close to the norm no scatter diagram for the community is given. Despite the fact that this Maich Shell Bed community constitutes a biospecies it is not deemed necessary to erect a new species, for the similarity to *Myalina magna* (Hind), discussed later, is so great that it may be assigned to that species. Such differences as do occur (value of H/L and musculature) may be due to the probable geographical isolation of the Maich Shell Bed community and to an evolutionary trend for H/L to increase with time, for the horizon of the lectotype of *M. magna* (350 feet above the M'Donald Lst. = Hosie Lst.), is considerably higher than that of the Maich Shell Bed (*Geol. Surv. Mem. Scotland*, Expl. of Sheet 23, p. 32).

Conditions of Sedimentation.

The fauna of the Maich Shell Bed, with the exception of two specimens referable to *Carbonicola* sp., is entirely marine. *Myalina* is not found in the position of growth and shows obvious signs of transportation. Only three specimens were found showing both valves in contact. *Lingula* is abundant, but frequently fragmentary, and occurs in separate layers more often than on the same bedding planes as *Myalina*, thus shedding little light on the ecological conditions which favoured the latter. The abundance of the two species *M. magna* (Hind) and *L. squamiformis* Phillips, together with rare occurrence of other fossils, is a distinctive character of this shell bed. In this respect, the abundance of individuals but the sparsity of genera, it resembles the upper part of the Johnstone Shell Bed in North Ayrshire. It may also be compared with the *Modiola* phases of the Avonian of Gower described by Dixon and Vaughan (1911, p. 512).

Myalina magna (Hind)

Naiadites magna Hind, 1895, pl. xix, fig. 17; *non* figs. 18, 19, 20.

I am indebted to Dr. J. Weir for showing that Hind's pl. xix, fig. 17, is distinct from the other figured specimens, and for the suggestion that it should be selected as the lectotype of "*N.*" *magnus*. Unfortunately the specimen is lost, but from its similarity to the Maich Shell Bed *Myalina* it is apparently referable to that genus, whereas the three remaining specimens (Hind, pl. xix, figs. 18–20) are undoubtedly

correctly referred to *Naiadites*. The following emended description of the species is based on the examination of over a hundred shells, the majority of which, however, are incomplete.

Diagnosis.—Shell sub-triangular, elongate with H/L 60 per cent. Valves nearly equally convex. Hinge-line (equivalent to the dorsal margin) (*vide* Trueman and Weir (in press)) long, over three-quarters the length of the shell. Ventral margin variable, gently convex, but rarely sigmoidal. Carinal swelling, rarely with a well defined crest, runs from the umbonal tip towards the postero-ventral angle in a sigmoidal curve. Posterior end rounded.

Dimensions.—Length, length of hinge, height and the angle β were measured in the standard directions (Leitch, 1941, p. 209, fig. 1). The angle α presents difficulties of measurement, reviewed by Trueman and Weir (in Press), and in its stead the angle γ (T. and W., loc. cit.) is used. Very few specimens were sufficiently complete to permit complete measurement. The figures for the norm of the community are compared with the averages of eight measured specimens from the same exposure, as well as those of the lectotype.

	L (mm.)	*H* (mm.)	*Dorsal Margin* (mm.)	γ	β
Hind, pl. xix, fig. 17.	41	30 (73%)	*c.* 34 (83%)	36°	108°
Norm (S. 6080)	38·0	22·5 (59·2%)	31·0 (81·6%)	35°	115°
Average for 8 meas. spec.	28	17 (61%)	22 (79%)	32°	108°

Description.—Umbones small, pointed, and terminal. Growth lines seldom seen. Hinge edentulous with a thickened striated hinge plate. Musculature not characteristic of *Myalina*. Three pits are present near to the anterior end. They lie in an oblique postero-dorsal—antero-ventral line. The lowest of the three, the anterior adductor scar, is the largest, relatively too large for typical *Myalina*. The other two pits, those of the pedal muscles, are nearly equal in size and rather larger than commonly found in *Naiadites*. The musculature of the anterior part of the shell is therefore intermediate in character between that characteristic of *Myalina* and *Naiadites* but is nearer the latter. The pallial line, at least in the anterior part of the shell, consists of a row of discrete pits.

Comparison.—The ratio of H/L is c. 10 per cent less in the case of the Maich Shell Bed forms, but dorsal margin/length, γ and β are closely comparable with the lectotype. Weir and Leitch (1942, fig. 3*f*) figure *N.* cf. *magna* from the roof of the Shale Coal of the Limestone Coal Group, from the Cumbernauld Bore, No. 1.

Myalina magna is superficially similar to the Lower Carboniferous species *M. verneuilii* (McCoy) and *M. flemingi* (McCoy). It may be distinguished from both, however, by its smaller size, its smaller value

for the ratio H/L, and its relatively longer dorsal margin. The holotype of *M. verneuilii*, from the Lower Carboniferous of Drumcurren in Ireland, was figured by McCoy (1844, pl. xii, fig. 19), and referred to the genus *Myalina* by Armstrong and Young (1871, p. 54). It was redrawn by Hind (1897, pl. iv, fig. 3), who gave a much more detailed description and noted its similarity to *M. flemingi*. Hind distinguished the Scottish specimens of *M. verneuilii* " . . . as being smaller than the type, and have the anterior lobe less well marked, though undoubtedly present ". The latter would appear to be very similar to *M. magna*, and two specimens have been examined as well as photographs of others figured by Hind. One (Hind, pl. iii, fig. 6) a left valve, is similar in all respects to *M. magna* except that the height is rather greater. It does not possess the highly developed anterior lobe shown in Hind's figure, but the umbo of the right valve simulates a lobe of the left. The other specimen examined (Hind, pl. iv, fig. 4), a right valve, the umbo of which is missing, resembles the sharply carinate variants of *M. magna*, to which species these two shells should undoubtedly be referred.

The apparent similarity of the shells under discussion to *Naiadites* has been reviewed (p. 449). The author originally thought that the Maich Shell Bed community included both *Myalina* and *Naiadites*, but detailed examination has not upheld this opinion. The distinction of possessing a fauna comprising both genera *may* belong to the horizon of the Dalry Blackband Ironstone at Dalry, from which J. Smith collected the material described and figured by Leitch (1941, p. 217, fig. 7). It is clear from Leitch's figure, and from examination of the material, that the shells from this bed differ markedly from the remainder of the figured *Naiadites tumidus* from the Brown Ironstone portion of the Lower Parrot and Ironstone of Bo'ness. All of the latter are undoubtedly referable to *N. tumidus*, but of the material from Dalry at least two specimens (Leitch, fig. 7*j*, and an unfigured specimen No. 7528) simulate *Myalina*. If the original locality and horizon at Dalry could be re-examined the possibility that there is continuous variation between *Myalina magna* and *Naiadites tumidus* could be reviewed. It is unfortunate that in Maich Water the Dalry Blackband Ironstone is apparently devoid of fossils, and that the Maich Shell Bed is not found in the vicinity of Dalry.

Distribution.—The Maich Shell Bed is of very limited extent; *M. magna* is here recorded at two localities. This species, as here defined, has previously been recorded from other horizons in the Limestone Coal Group of Bankend, Lesmahagow, and Garngad Road, Glasgow.

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On the presence of the Upper *Dibunophyllum* Zone (D_3) near Glynneath, South Wales

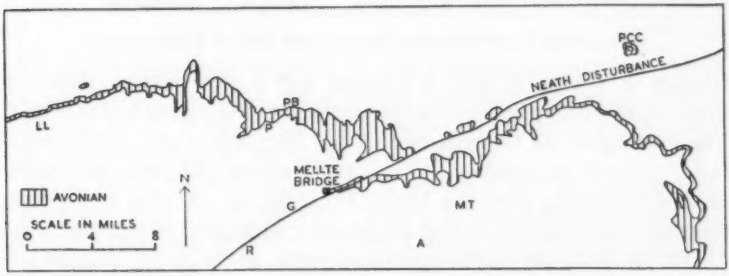
By T. R. Owen and D. G. Jones

Abstract

Beds near Glynneath previously believed to be of Middle *Dibunophyllum* Zone (D_2) age are claimed to belong to the Upper *Dibunophyllum* Zone (D_3). These beds are described, and the implications of the position of this new locality on the Neath Disturbance are discussed.

Introduction

NAMURIAN overstep over the eastern portion of the South Wales Coalfield results in the progressive disappearance, in an easterly direction, of the various divisions of Avonian strata (Dixey and Sibly, 1918, plate xv ; Pringle and George, 1948, fig. 19 ; George, 1955, fig. 1 and p. 312). On the North Crop this overstep is first detected near Pwll Byfre, about one and a half miles east of Penwyllt, where the Upper *Dibunophyllum* Zone (D_3) disappears (George, 1927, p. 79). These beds, known as the Upper Limestone Shales and consisting of characteristically alternating bands of dark shales and impure limestones, rarely reach a thickness of 20 feet along the North Crop (George, 1927, p. 79; Robertson, 1933, p. 29). Weathering readily to rottenstone or fine silica sand, they have been extensively dug for use as a polishing powder. The exposures are rare and rather unsatisfactory (George, 1927, p. 42).



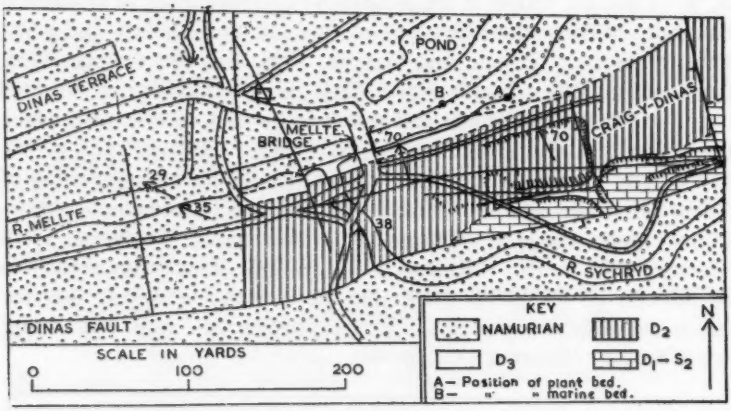
Text-fig. 1.—Position of Mellte Bridge on the North Crop of the South Wales Coalfield. Key to abbreviations :—A—Aberdare ; G—Glynneath; LL=Llandebie; MT—Merthyr Tydfil; P—Penwyllt; PB—Pwll Byfre; PCC—Pen-cerig-calch ; R—Resolven.

During a revision of the Avonian–Namurian junction at the head of the Vale of Neath, the writers have found that a limestone outcrop formerly regarded as belonging entirely to the Middle *Dibunophyllum* Zone (D_2) also includes beds of the Upper *Dibunophyllum* Zone (D_3).

In view of the excellent state of the exposure, in marked contrast to the unsatisfactory exposures of similar beds elsewhere along the North Crop, a full description of the D_3 beds is given below. This new record of the Upper Limestone Shales marks the most easterly occurrence of the formation along the North Crop of the Coalfield. As shown below, the position of the exposure, on the line of the Neath Disturbance, is of some significance and furnishes further evidence of early movement along the belt.

Description of the Exposure

The beds are exposed on the south bank of the River Mellte at the confluence of that river with its tributary, the Sychryd. This locality



Text-fig. 2.—Geological map of the Mellte Bridge area.

(known as Mellte Bridge) is situated half a mile east-north-east of Pont-Nedd-Fechan and two miles north-east of Glynneath (Text-fig. 1). The outcrop of the D_3 beds extends for 230 yards from a north–south fault, west of the confluence, to a point about 150 yards east-north-east of the bridge over the Mellte (Text-fig. 2). At this easternmost position, the Upper Limestone Shales are overstepped by the Namurian.

The D_3 beds dip north-north-westwards at 55 to 70 degrees and a complete section of the formation is revealed on the right bank of the Sychryd at its confluence with the Mellte. The junction with the Millstone Grit can be seen in the bed of the Mellte, 3 feet beyond the end of the section, whilst the Upper Limestone Shales are clearly underlain by 80 feet of massive, dark, D_2 limestone, fully exposed in the gorge of the Sychryd. The total thickness of the D_3 beds can therefore be measured and found to be 22 to 25 feet, the variation resulting from slight thickening of individual beds along the strike.

A small dip fault, with a westerly downthrow of 10 feet, displaces the outcrop of the D_3 beds at a rivulet just west of the Sychryd-Mellte confluence; beyond this fault the thickness of the formation is reduced to about 15 feet.

The detailed succession in this main section is as follows:—

		ft.	in.
	Basal Conglomerate of the Millstone Grit	–	–
23.	Dark shale with a middle rib of limestone (these beds are seen beneath the water)	3	0
22.	Dark, muddy limestone	1	0
21.	Dark shale		10
20.	Medium-grey, crinoidal limestone	1	0
19.	Dark, muddy limestone	1	0
18.	Dark shale		4
17.	Dark, muddy limestone	1	0
16.	Dark shale		6
15.	Dark, muddy limestones	2	0
14.	Dark, muddy limestone	1	8
13.	Coarse, crinoidal limestone		8
12.	Dark, muddy limestone		6
11.	Dark shale		3
10.	Crystalline, crinoidal limestone	2	0
9.	Dark shale		6
8.	Dark blue limestone	1	2
7.	Dark shale		3
6.	Dark, muddy limestone		8
5.	Dark shale		6
4.	Dark blue, crinoidal limestone		9
3.	Dark shale		4
2.	Dark crinoidal limestone	1	3
1.	Dark shale	2	2
	Massive medium to dark grey D_2 limestones with numerous calcite veins	–	–
	Total	23	4

The shales are somewhat calcareous and sometimes pyritous. Small pins and nodules of pyrite occur also in the muddy limestone (china-stone) bands. Crinoid ossicles in the crinoidal bands are sometimes large, as for example at the base of bed 20.

Fossils occur in the shales and limestones but are particularly abundant in beds 13, 20, and 22. They are mainly brachiopods, but zaphrentid corals are common in bed 14, being particularly noticeable on its upper surface.

The following fauna has been collected from the section described above:—

Zaphrentids including *Triptophyllites oystermouthensis** (Vaughan)
Athyris sp.
Brachythyris sp.
Buxtonia scabricula (Martin)
Chonetes spp.

Crurithyris ? sp.
Lingula mytiloides Sowerby
Martinia cf. *multicostata** George
Orbiculoidea nitida (Phillips)
Phricodothyris sp.
Productus (*Eomarginifera*) *longispinus* Sowerby
Productus cf. *martini* Vaughan
Productus productus (Martin)*
Productus (*Dictyoclostus*) *sulcatus* Sowerby
Pugnax cf. *pugnus* (Martin)*
Schellwienella cf. *crenistria* (Phillips)
Spirifer oystermouthensis Vaughan*
Bellerophon sp.
Bryozoan fragments
Crinoid ossicles
Fish fragments, chiefly scales
Ostracods*
Griffithides cf. *barkei* Woodward

Productus (*Eomarginifera*) *longispinus* is particularly common in bed 22, *Schellwienella* and *Martinia* in bed 20.

Zonal Position of the Described Beds

The alternating character of the beds occurring in the above section strongly supports their correlation, on purely lithological grounds alone, with the Upper Limestone Shales of the North Crop between Kidwelly and Penwyllt (cf. George, 1927, pp. 40, 50, 79), the Upper Limestone Shales in the west of the Vale of Glamorgan (cf. George, 1933, pp. 226, 251), and the " Black Lias " of Oystermouth, Gower (Dixon and Vaughan, 1911, pp. 491–3). George has previously compared the Upper Limestone Shales of the North Crop and of the Vale of Glamorgan with the Black Lias of Gower (1933, p. 226). Robertson (1933, p. 60) has noted the pyritic character of the shale in the Rottenstones at Penwyllt.

The faunal evidence is, however, even more convincing. The fauna is quite distinct from that of the underlying D_2 limestone and is closely comparable with that of the Upper Limestone Shales of the North Crop, the Vale of Glamorgan, and Gower. Of the seventeen forms which occur in the Vale of Glamorgan (George, 1933, pp. 251–2), eleven occur at Mellte Bridge. Of the thirteen forms of brachiopods occurring at Penwyllt (George, 1927, p. 80), nine are also present in the new locality; another form, *Buxtonia scabricula*, is present at Mellte Bridge and at

* The forms marked with an asterisk have been identified by Professor T. Neville George.

Mynydd-y-Gareg, near Kidwelly (George, 1927, p. 51). Seven brachiopod forms are common to both Gower (Dixon and Vaughan, 1911, p. 550), and the Mellte. It will be noted that whilst Zaphrentid corals are absent at Penwyllt, they are common at Mellte Bridge.

The distinctive character of this D_3 fauna has been previously stressed by George (1933, p. 253), who added: " The elevation of the Upper Limestone Shales to the rank of a zone in the Avonian sequence therefore appears to be completely justified on both faunal and lithological grounds . . . To avoid further confusion, I propose discarding the term D_{2-3} and employing Sibly's D_3 (1920, pp. 79, 81) for the zone " (1933, p. 253).

Rayner (1953, pp. 292–5) doubts the validity of this zone, but the writers agree with the views of Professor George. It is claimed that the beds in the Mellte Bridge section belong to the Upper *Dibunophyllum* Zone (D_3) and mark the most easterly recorded occurrence of the Zone along the North Crop of the South Wales Coalfield.

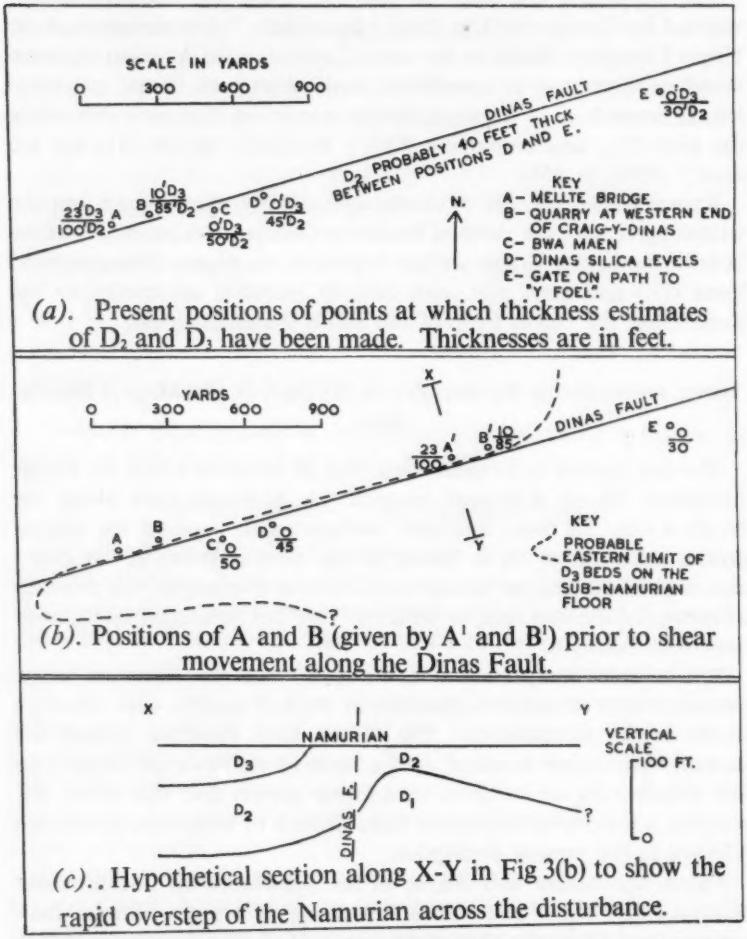
Implications of the Revised Zonal Position of the Mellte Bridge Beds

The new locality is 5½ miles south-east of the point where the Upper Limestone Shales disappear beneath the Millstone Grit along the North Crop. Its more southerly position partly explains the slightly greater thickness of D_3 at Mellte Bridge than at Penwyllt. It might also explain the greater faunal comparison (for example, the presence of corals) of the new locality with the Vale of Glamorgan and Gower than with Penwyllt.

This simple interpretation is, however, not the complete story. One must also consider the position of the new locality with reference to the Neath Disturbance. The writers have therefore studied the Avonian–Namurian junction at the head of the Vale of Neath (the full descriptions to be given in another paper) and this study has revealed a number of important features, two of which are considered relevant to the present description.

Firstly the nature and degree of the sub-Namurian unconformity in the Craig-y-Dinas and Mellte Bridge region is more complex than was previously thought. One of the writers (T. R. O.) has already shown that the D_2 beds are of varying completeness and thickness in the vicinity of the Neath Disturbance, movement along which had therefore occurred long before the Armorican orogeny (Owen, 1954, pp. 351–3 and fig. 9). The discovery of D_3 beds at Mellte Bridge, underlain by an appreciable thickness of D_2 limestones, now makes possible an even more detailed analysis of the sub-Namurian floor in this region.

The writers now believe that the Middle *Dibunophyllum* Zone (D_2) at Mellte Bridge and at the western end of Craig-y-Dinas, both on the north side of the Dinas Fault, is 80 to 100 feet thick. Moreover, D_3 is present here. In the same district, but on the south side of the


SCALE IN YARDS
0 300 600 900
DINAS FAULT
D2 PROBABLY 40 FEET THICK BETWEEN POSITIONS D AND E.
KEY
A- MELLTE BRIDGE
B- QUARRY AT WESTERN END OF CRAIG-Y-DINAS
C- BWA MAEN
D- DINAS SILICA LEVELS
E- GATE ON PATH TO "Y FOEL".
N.
(a). Present positions of points at which thickness estimates of D2 and D3 have been made. Thicknesses are in feet.
YARDS
0 300 600 900
DINAS FAULT
KEY
PROBABLE EASTERN LIMIT OF D3 BEDS ON THE SUB-NAMURIAN FLOOR
(b). Positions of A and B (given by A' and B') prior to shear movement along the Dinas Fault.
NAMURIAN
VERTICAL SCALE
100 FT.
0
DINAS F.
(c). Hypothetical section along X-Y in Fig 3(b) to show the rapid overstep of the Namurian across the disturbance.

TEXT-FIG. 3.—Variations in thickness of D_2 and D_3 along a portion of the Neath disturbance.

fault, the D_3 beds are definitely absent and, moreover, the D_2 succession is much thinner, being not more than 50 feet thick. Furthermore, the uppermost D_2 beds seen to the south of the Dinas Fault on Bwa Maen and near the Dinas Silica Levels are particularly striking in containing lenses, pipes, and sheets of very coarse conglomeratic material. This

evidence suggests uplift along the Disturbance, certainly at the close of Avonian times, and probably also (though in a more localized manner) even during D_2 times.

The thickness variation of the *Dibunophyllum* beds across the Disturbance is even more striking when one allows for the sinistral displacement believed to have occurred along the Dinas Fault during the Armorican Orogeny (Owen, 1954, p. 350). Text-fig. 3 shows (*a*) the present positions of the points where thickness estimates have been made for the D_2 and D_3 beds in the vicinity of the Disturbance, and (*b*) the probable positions of those localities prior to the sinistral shear movement. The eastern limit of the D_3 beds on the sub-Namurian floor must have been considerably disrupted, with a marked tongue of D_2 extending south-westwards, in the vicinity of the Disturbance (Text-fig. 3*b*). Text-fig. 3*c* illustrates the varying intensity of the sub-Namurian unconformity across the Neath Disturbance.

The second interesting feature of the Avonian–Namurian contact in this district concerns the age of the lowest Namurian strata. It has been previously thought that these strata display overlap as they are traced eastwards from Llandebie and the River Twrch (Ware, 1939, pp. 174–5; Pringle and George, 1948, fig. 19). The age of the lowest Namurian strata at the head of the Vale of Neath has been considered to be no older than R_1 (Evans and Jones, 1929, p. 168; Pringle and George, 1948, fig. 19) or late H (Ware, 1939, p. 175).

The D_3 shales and limestones at Mellte Bridge are succeeded by the conglomerates, quartzites, and thin shale bands of the Basal Grits, the lowest formation of the Namurian in this area. The lowest beds of the formation are well exposed on the banks of the Mellte above the bridge, and two thin shale bands, one 15 feet and the other 32 feet above the base of the Grits have yielded fossils. The lower band (A in Text-fig. 2) contains only plants of which the most important and distinctive type is *Lyginopteris* (*Calymmatotheca*) *stangeri* (Stur). The higher band (B in Text-fig. 2) contains *Orbiculoidea* sp. and fish-scales. Both these bands are well below the marine horizon containing *Reticuloceras inconstans*, already known to occur in this area.

The presence of these two new bands near the base of the Millstone Grit merits revision of the age of the basal beds. The occurrence of *Lyginopteris* (*Calymmatotheca*) *stangeri* (Stur) suggests a zonal position for that bed "not above the base of the *Homoceras* Zone" (Dix, 1933, p. 163). In Carmarthenshire, Ware (1939, p. 174) has found *Lyginopteris* (*Calymmatotheca*) *stangeri* (Stur) in thin shale only about 12 feet above a marine band containing a fauna characteristic of a low horizon in E_2. The lowest beds of the Basal Grits at the head of the Vale of Neath may therefore be older than was previously thought. Moreover, the presence of the Upper *Dibunophyllum* Zone

at Mellte Bridge appreciably narrows the gap between the Avonian and the Namurian in that locality.

The authors wish to express their thanks to Professor T. Neville George and Professor Duncan Leitch for their advice and their sustained interest in the work of which this paper forms a part. Professor George has kindly identified some of the fossils. The writers also thank Mr. T. C. Marchant for his kind assistance in photographing exposures and preparing rock and fossil sections.

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The Western Longmyndian Rocks of the Shrewsbury District

By T. H. WHITEHEAD

ABSTRACT

Evidence from graded bedding and other sedimentary structures has shown that in the eastern outcrop of the Western Longmyndian rocks of the Shrewsbury area the stratigraphical base lies towards the east. Since in the western outcrop of these rocks the base is believed to lie towards the west, Professor Whittard's suggestion that the Western Longmyndian rocks are folded into a syncline, with the " Oakswood Group " representing a repetition of the " Bayston Group ", is accepted. The form and age of the fold are briefly discussed.

IT has long been recognized that those of the pre-Cambrian rocks of Shropshire to which Callaway (1888) gave the name " Longmyndian " are divisible into two main groups or " Series ". These were named by Charles Lapworth (1894) the Eastern Longmyndian, or Grey Shale Series, and the Western Longmyndian, or Red Sandstone Series and, later (1910) respectively the Stretton Series and the Wentnor Series.

J. F. Blake (1890), who regarded the Red or Western Series as of Cambrian age, divided them into three groups, consisting of an eastern and a western group of sandstones, with an intervening group of " purple slates ". Lapworth (1910) divided the Wentnor Series into two: an eastern division of " red and grey grits with the three zonal conglomerates of Stanbach, Darnford, and Haughmond ", which he called the Bayston Group, and a western division of " red and purple grits and shales, with conglomerates "—the Ratlinghope Group. Lapworth's Ratlinghope Group includes the " purple slates " of Blake.

In the Shrewsbury Memoir (1938) of the Geological Survey a return to a threefold division of the Wentnor Series was made. The groups were named, from east to west : the Bayston Group, corresponding approximately to Lapworth's group of that name, the Bridges Group, corresponding approximately to Blake's " purple slates ", and the Oakswood Group, comprising grits and conglomerates which crop out to the west of the Bridges Group.

Blake referred to a suggestion of a synclinal structure in the Western Longmyndian (" Cambrian ") rocks, citing Callaway's paper of 1882. There seems to be no such suggestion in Callaway's paper but, in any case, Blake rejected the idea of a syncline (Blake, 1890, pp. 387 and 400). From the fact that Lapworth included Blake's " purple slates " in his Ratlinghope Group it may be inferred that he, also, rejected

the idea of a syncline and regarded his Bayston and Ratlinghope groups as representing a normal succession, without repetition, of which the " apparent descending sequence " was from west to east (Lapworth and Watts, 1910, p. 748). Curiously enough, however, this paper is illustrated by a section (figs. 123 and 124, pp. 744–5) in which the Western Longmyndian rocks are shown as if folded into a syncline. This section was first published in 1894 (Lapworth and Watts, 1894), and again in 1925 (Watts, 1925). In none of these papers is there any explanation of why the section was so drawn or any mention of a synclinal structure in the Western Longmyndian. Again, E. S. Cobbold (1900, Plate ii) has a section in which the Western Longmyndian is shown as a syncline, with " Upper Longmyndian Shales " resting upon " Upper Longmyndian Sandstone and Conglomerate "; but here, also, no reference to a synclinal structure is given in the text. In neither Lapworth's nor Cobbold's section do the dips shown in the Western Longmyndian rocks bear much relation to those observable in the field.

In the Shrewsbury Memoir (1938) the succession in the Wentnor Series was treated as a normal, unrepeated one, but evidence was given that the sequence might be upward from west to east (pp. 11–13).

Professor Whittard (1952, p. 149),[1] on the other hand, has revived the suggestion that the rocks of the Wentnor Series are folded into a syncline and that the Bayston Group is repeated in the form of the Oakswood Group, though he acknowledged that the arguments in favour of this view were " highly conjectural ".

Evidence obtained during the past two years has, however, provided support for Professor Whittard's suggestion. At three places within a radius of 5 miles from Shrewsbury sedimentary structures in the Western Longmyndian rocks have been observed which, in all cases, indicate that their base is towards the east or south-east.

One of the places examined was the quarry to the east of Haughmond Abbey, about 4½ miles north-east of Shrewsbury. Here the writer had the good fortune to be accompanied by Dr. G. H. Mitchell. The beds in this quarry are the grits between the Haughmond and Darnford Conglomerates (the " Castle Sandstones " of T. C. Cantrill, 1925, p. 6). Several exposures of graded and cross-bedding were found. In the majority of cases the base was clearly towards the east. This was shown by grading from coarse to fine towards the west, by relatively sharp terminations of coarser laminae towards the east, and by

[1] The present writer deprecates the confusing use in this paper (pp. 148–9, 150; also James, 1952, p. 199) of the term " Longmynd " to embrace the whole of the Longmyndian outcrop south of Shrewsbury. The Longmynd is a well defined physical feature, named on published maps, which does not extend north of High Park or west of Ratlinghope, Asterton, and Myndtown.

erosion planes on the east side. In one or two cases cross-laminations appeared to be cut off abruptly on the west side, but to descend in catenary curves towards the east. In other places bands of purple mudstone could be seen to have been eroded during the deposition of the grit following them on the west side. In a few cases the direction of grading was doubtful, but in none was it clearly upwards towards the east.

Cantrill's opinion (Shrewsbury Memoir, p. 11) that in the Darnford Conglomerate the ascending order was in an eastward direction is at variance with the evidence obtained in the quarry. He drew his conclusion from " a tendency for the size and frequency of the pebbles to diminish in an eastward direction ". The Darnford " Conglomerate ", however, is actually a pebbly and conglomeratic belt about 400 feet thick (i.e. of about the same order of thickness as the whole of the Bunter Pebble Beds formation). No safe conclusion as to the order of deposition can be drawn from the overall distribution, in size and frequency, of pebbles in a belt of this thickness; only individual lenses of conglomerate could provide reliable evidence. The writer and Dr. Mitchell examined exposures of the Darnford Conglomerate south of the Shrewsbury–Newport road without finding unequivocal evidence as to the side on which the base of conglomeratic lenses occurred. In one place, however, about 100 yards from the southern end of the outcrop, grits interbedded with the pebbly rock did appear to show graded bedding upwards towards the west, the rhythm being repeated three or four times within the exposure. Moreover, on a subsequent visit to Haughmond Hill, it appeared to the writer that in the Haughmond Conglomerate, as exposed at the southern end, there was a general tendency for the pebbles to decrease in size towards the west and that there were some indications of grading in individual lenses of conglomerate, with the bases towards the east.

The conclusion that on Haughmond Hill the base of the Western Longmyndian rocks is towards the east is of particular interest in relation to Mr. Challinor's observation (1948) that in the quarry just north of Criftin the Eastern Longmyndian rocks have their base towards the west and are not inverted. The Eastern Longmyndian rocks of Haughmond Hill, from the base of the Bayston Group at least as far east as Criftin, probably all belong to the Burway Group. But the apparent thickness of this group on Haughmond Hill is nearly twice as great as that on the Longmynd near Church Stretton. This suggests that in the former locality there is repetition by folding on a considerable scale. The writer is now inclined to agree with Cantrill that there is no fault between the " purple " and " green " beds of Haughmond Hill (cf. Callaway, 1891, p. 112; Pocock and

Whitehead, 1948, p. 24), and to regard the junction between the Bayston Group and the Eastern Longmyndian as an unconformity.

Another place examined was Sharpstone Quarry, about 2¼ miles south of Shrewsbury. Here, again, the beds are grits between the Haughmond and Darnford Conglomerates (Shrewsbury Memoir, p. 48). The evidence from graded bedding in this quarry seemed to indicate an upward succession towards the north-west, but no examples were found as clear as those in the Haughmond quarry. Evidence from contemporaneous erosion was more convincing. In one place, near the middle of the east face, a band with large fragments of purple mudstone in rather coarse grit was found. This band was in contact, towards the south-east, with finer grit. The junction was sharp and irregular, like an erosion plane. Many of the larger mudstone fragments lay parallel with the general direction of the bedding and some showed internal lamination with the same general direction. The mudstone fragments became less numerous, smaller and more widely separated by gritty material towards the north-west, in which direction the band seemed to tail off into a coarse grit which had sporadic mudstone fragments within a thickness of about 2 feet. This seems, then, to be a clear case of the erosion of a mudstone bed by water bringing in coarser material, the base being now towards the south-east.

The third locality examined was a disused quarry on Stapleton Common, about 5 miles S.S.W. of Shrewsbury. The beds here are the grits to the west of the Stanbatch Conglomerate. Here there are several clear examples of graded bedding in both the north and the south faces of the quarry. In a few cases the direction of grading was doubtful, but in most it was clearly upwards towards the west. The grading is shown by the passage from relatively coarse, gritty sandstone up into finer material, reaching probably siltstone grade, followed by a sharp, usually irregular and erosive junction, above which the coarser material sets in again.

Extrapolation from evidence of the kind described above is attended by some risk (Whitehead, 1948), but the consistent results given in the three localities seem to justify the conclusion that in the Shrewsbury area the base of the Bayston Group is everywhere towards the east.

On the other hand, there is evidence that, between Plealey and Farther Gatten, the Oakswood Group has its base towards the west (Shrewsbury Memoir, p. 12), and the same conclusion has been drawn in the Linley area (James, 1952, p. 198). The simplest explanation of this opposing arrangement of the Bayston and Oakswood groups is that suggested by Professor Whittard, namely that they represent the same group repeated by a synclinal fold. Final proof of the stratigraphical equivalence of the Bayston and Oakswood groups would require that the one should be traced into the other round the " nose "

of the syncline, but this evidence, if it exists, is buried beneath the Triassic rocks somewhere north of Shrewsbury.

The Bayston and Oakswood groups do show some differences (Shrewsbury Memoir, p. 54), but, having regard to the evidence given above, to maintain on this account that they are stratigraphically distinct would involve complications of structure for which there is no warrant. It is simpler, following Professor Whittard, to attribute the differences to original lateral variation. It would appear that the variation across the syncline is greater than that parallel to its axis.

As indicated above, the axis of the syncline is concealed to the north of Shrewsbury. It may be in the neighbourhood of Battlefield and, judging by the inversion of the Bayston " Group " in the northern part of Haughmond Hill, the axial plane is probably inclined towards the east. Farther south the plane may, for a short distance, become vertical or slightly inclined towards the west.[1] But, from some point under Shrewsbury to the neighbourhood of Pulverbatch, the inclination of the axial plane is easterly, since the eastern limb is inverted. Near Pulverbatch the plane would seem to be approximately vertical, but farther south the inclination is towards the west, the western limb of the fold being inverted. This condition seems to hold as far south as Chittol and Linley (James, 1952, p. 199).

There is little evidence as to the date of the folding that gave rise to the syncline in the Wentnor Series. It may well be pre-Cambrian and is probably pre-Caradocian, for the Western Longmyndian rocks near Pontesford had already acquired a high dip when the Caradocian strata were laid down (Shrewsbury Memoir, p. 11). The deformation of the syncline which resulted in the variations in the direction of the axis and the inclination of the axial plane was, perhaps, contemporary with the formation of the transverse tear faults that affect the Longmyndian outcrop. If so, its date is probably post-Caradocian and pre-Valentian (Shrewsbury Memoir, p. 176; Whittard, 1952, p. 186).

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[1] On the Shrewsbury Sheet (152) of the one-inch geological map westerly inclinations in the Longmyndian rocks of Haughmond Hill are indicated by dips of over 90° in the opposite direction.

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RAGLETH HOUSE,
LITTLE STRETTON,
SHROPSHIRE.

Supposedly Colpate Pollen Grains from the Jurassic

By R. A. COUPER

(PLATES XX AND XXI)

ABSTRACT

Some Mesozoic spores and pollen grains claimed in a recent publication to exhibit angiosperm-like features are discussed. It is suggested that *Poroplanites* Pflug, is actually a trilete fern spore. The " germinal apparatus " of the *Poroplanites* type is simply an optical section of the characteristic folding of a lobe of a trilete spore, flattened along the polar axis and seen in equatorial view. It is shown that Pflug's *Poroplanites* type can be reproduced almost exactly in the trilete spores of a living tree fern. *Classopollis* Pflug, *Circumpollis* Pflug, and *Canalopollis* Pflug are pollen grains with distinct annular thickening, similar to the pollen grains of the Jurassic araucarian, *Pagiophyllum connivens* Kendall.

INTRODUCTION

PFLUG (1953), described and illustrated a number of spores and pollen grains which he claimed exhibited angiosperm-like germinal apertures, although he pointed out that his conception of " angiosperm-like pollen " does not coincide with the term " angiosperm-pollen " as normally used. Four of his genera, *Poroplanites*, *Classopollis*, *Circumpollis*, and *Canalopollis*, are discussed below.

1. THE *POROPLANITES* TYPE

Trilete spores in which the intine has been lost and which have been subjected to pressure are more or less collapsed, generally along either their equatorial axis, as in Pl. XX, fig. 1, or along their polar axis (Pl. XX, figs. 2–7). The feature described by Pflug as the " germinal apparatus " of the *Poroplanites* type is an optical section of the characteristic folding of a lobe of a trilete spore, flattened along its polar axis and seen in equatorial or oblique equatorial view.

The writer has reproduced almost exactly Pflug's *Poroplanites* type in present-day spores, by boiling lobate, trilete spores (such as those of most living tree ferns) in 10 per cent NaOH for some ten minutes to destroy the intine, mounting in glycerine jelly and then flattening the spores by pressure on a cover slip. About 20 per cent of the spores thus treated are suitably orientated to show the foldings of a lobe corresponding to Pflug's " germinal apparatus ".

Pl. XX, figs. 1–5, are photomicrographs of spores of *Cyathea pubescens* Mett. ex Kuhn., a living tree fern from Jamaica, treated as described above. Fig. 2 should be compared with pl. 15, figs. 37, 38, and figs. 3–5 with text-fig. 2 (p. 68) of Pflug's paper. It was not possible to flatten the spores of *C. pubescens* to the same degree as Pflug's Mesozoic specimens, but Pl. XX, figs. 6 and 7, which are equatorial views of spores of the Jurassic fern *Dictyophyllum rugosum* L. and H. described by

Harris (1944), match *Poroplanites* very closely. In particular, figs. 6 and 7 should be compared with Pflug's text-fig. 2 (p. 68) and pl. 15, fig. 34 respectively. It is interesting that although Pflug's fig. 34 is not particularly clear there appears to be a raised commissure similar to that of *D. rugosum*. It can also be noted here that the " curious loops " described in the spores of the Jurassic tree fern *Dicksonia mariopteris* by Wilson and Yates (1953) are also the foldings of the lobes of a flattened trilete spore seen in optical section.

Support is lent to the writer's interpretation of the *Poroplanites* type by the fact that although spores with a germinal apparatus of the type ascribed to *Poroplanites* should present a very characteristic appearance in polar view, Pflug gives no polar views except in his pl. 15, fig. 5, which is so indistinct that no structure can be seen. Also, in none of the oblique equatorial views is there any evidence of " cavernae " developed around the other two arms of the triradiate scar. In fact, in the diagnosis of the new species *Poroplanites porosinuosus*, Pflug commented (p. 88) that the opening of one " Y mark " is usually better developed than the other two.

It is possible that polar views of the spores called *Poroplanites* have been considered by Pflug to be different species. For example, some of the spores figured on his pl. 18 as *Duplosporis* and *Semisporis* could well be polar views of *Poroplanites*. The so-called " distal Y marks " of the *Duplosporis* type appear from the photomicrographs to be no more than folds in the exine simulating a second trilete mark. Such folding has been noted occasionally by the writer in fossil spores ranging in age from Jurassic to Pleistocene.

It should be noted that the comparison made in this paper between the spores of *Dictyophyllum rugosum* and *Poroplanites* does not imply that they are closely related, but only that the spores are of the same general type. In view of the fact that the diagnosis of *Poroplanites* is almost certainly based on the erroneous observation of a trilete spore in equatorial view, it is suggested that *P. porosinuosus* Pflug and *P. napiformis* Pflug be transferred (at least until further evidence of their affinity is forthcoming) to the form genus *Trilites* Cookson ex Couper. For discussion of this genus see Couper (1953, p. 29).

2. The *Classopollis*, *Circumpollis*, and *Canalopollis* Types

Pollen grains which appear identical with those figured by Pflug as *Classopollis*, *Circumpollis*, and *Canalopollis*, are abundant in samples examined by the writer from the Middle Deltaic Series of Middle Jurassic age exposed at Yons Nab, near Gristhorpe, Yorkshire. These pollen grains are most characteristic and can be recognized from almost any angle by a marked thickening running around the equatorial region. This annular thickening appears in slightly different forms

according to the orientation of the grain and possibly to a certain extent on the state of preservation, which in turn may depend on the stage of maceration of the sample.

Pl. XX, fig. 8, and Pl. XXI, fig. 1, clearly show the annular thickening and should be compared with pl. 16, figs. 39–41 (tetrads of *Classopollis*), in Pflug's paper. The annular thickening is made up from some four to seven bands of endexinal thickening; each band is about 1μ wide and together they form a zone from 5 to 8μ wide running around the equatorial region. In some specimens, however, each band instead of being continuous is formed of more or less discrete granules arranged linearly. Occasional specimens seen by the writer show both continuous and discrete types of thickening in the one specimen, suggesting the two types are of no diagnostic value. They are possibly due to differences in the state of preservation.

Pl. XXI, figs. 2 and 3, show a transition in the same specimen of the annular bands of thickening just described to another common appearance of the annular thickening. Due to the orientation of the grain, or perhaps in some cases to the state of preservation, the bands appear to have coalesced to form a continuous zone. This is the appearance in most polar or near polar views (Pl. XXI, figs. 9 and 10). These two specimens match very closely *Circumpollis philosophus* (pl. 17, figs. 33–6), " Siegelsum N Typus " (pl. 17, figs. 38–40), and *Canalopollis maturus* (pl. 17, figs. 59–60) in Pflug's paper.

A rare, though most characteristic appearance is that shown in Pl. XXI, figs. 4–8. The comparatively thin exine of the polar regions appears to have torn away from the thickened equatorial region. The line of parting has the appearance of a colpus and is almost certainly the " rimula " of Pflug. Figs. 6–8 in particular match extremely well *Classopollis classoides* (pl. 16, figs. 22–4 and 29–31), and there can be little doubt they are closely related, if not identical, forms of pollen.

Kendall (1952) figured and described pollen grains from an araucarian male cone attributed to *Pagiophyllum connivens* Kendall, from Jurassic rocks at Eston, Yorkshire. Unfortunately the pollen preparation is rather deeply stained and a little under-macerated. Also most of the pollen grains are still stuck together in the pollen sac and are not clearly displayed. Examination under oil immersion reveals, however, that they are almost certainly identical with those pollen grains figured in this paper from the Gristhorpe Middle Deltaic. They show clearly an annular thickening and have a similarly sculptured exine. Also their size range (28 to 37μ) is similar to that of the Gristhorpe specimens (28 to 40μ). Pl. XXI, figs. 11 and 12, show two of the clearer specimens from Kendall's type slide.

After comparison with the pollen grains attributed to *P. connivens* there is no reason to suppose that the somewhat varied range of pollen

grains of the *P. connivens* type from the Gristhorpe Middle Deltaic represents more than one species. Similarly, considering the specimens figured by Pflug on pls. 16 and 17, the following appear to be closely related to, if not identical with, the *Pagiophyllum connivens* type:—

Pl. 16, figs. 16–19: *Classopollis declassis.*
Pl. 16, figs. 20–5, 29–37: *C. classoides.*
Pl. 16, figs. 39–41: tetrads of *Classopollis.*
Pl. 17, figs. 28–30: *Circumpollis pharisaeus.*
Pl. 17, figs. 31–6: *C. philosophus.*
Pl. 17, figs. 38–40: " Siegelsum N Typus."
Pl. 17, figs. 46–7: " Poroplaniter Typus."
Pl. 17, figs. 48–60: *Canalopollis maturus.*

From the above list it can be seen that in the writer's opinion nearly all the specimens attributed by Pflug to various species of *Classopollis*, *Circumpollis*, and *Canalopollis* as well as those called " Siegelsum N Typus " and " Poroplaniter Typus " are closely related pollen grains, belonging probably to an extinct member of the Araucariaceae.

Acknowledgments

The writer wishes to thank Mr. N. F. Hughes, Sedgwick Museum, Cambridge, and Dr. H. Godwin, Botany School, Cambridge, for helpful criticism of this paper. Dr. H. Hamshaw Thomas and Professor T. M. Harris provided some of the material for this work, and through the courtesy of the British Museum (Natural History) the writer has had the opportunity of examining type material of *Pagiophyllum connivens* and *Dictyophyllum rugosum.* This study was carried out while in receipt of a New Zealand National Research Fellowship.

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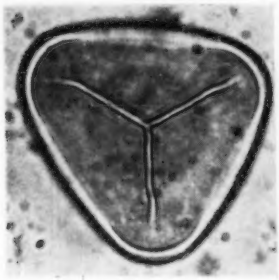

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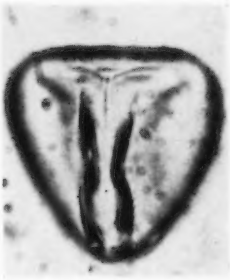

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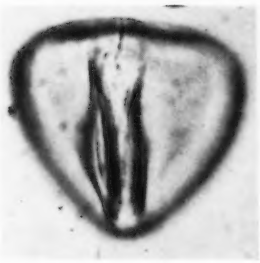

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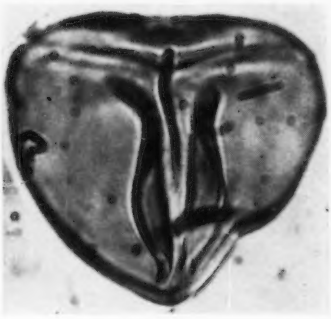

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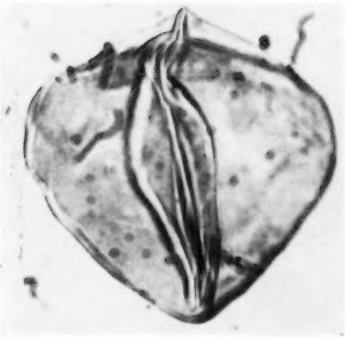

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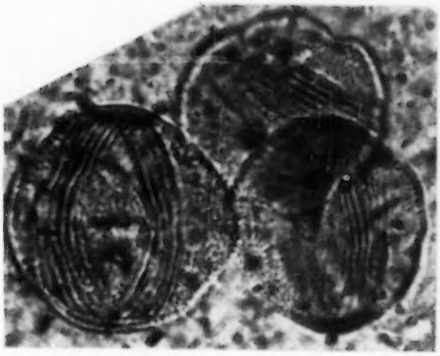

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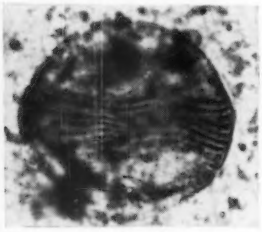
RECENT AND FOSSIL SPORES AND POLLEN GRAINS.



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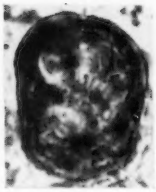

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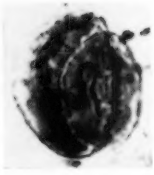

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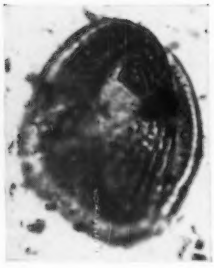

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FOSSIL POLLEN GRAINS.

EXPLANATION OF PLATES XX AND XXI

All illustrations are from untouched photomicrographs and all are magnified 800 ×. Specimens prefixed by " L " and " K " are deposited in the Sedgwick Museum, Cambridge.

PLATE XX

FIG. 1.—Spore of *Cyathea pubescens* Mett. ex Kuhn. Recent, Jamaica. Polar view. L. 832 a.

FIGS. 2–5.—Spores of *C. pubescens*. Equatorial and oblique equatorial views. L. 832 b–d.

FIG. 6.—Spore of *Dictyophyllum rugosum* L. and H. Oblique equatorial view. K 857 b from fertile specimen from Gristhorpe (collected by H. H. Thomas).

FIG. 7.—Spore of *D. rugosum*. Equatorial view. K 857 c.

FIG. 8.—Group of pollen grains (? part of tetrad) of the *Pagiophyllum connivens* type. K 858 from sample 1 foot above top of Millepore Bed, near Yons Nab, Gristhorpe.

PLATE XXI

FIG. 1.—Pollen grain of the *Pagiophyllum connivens* type. Equatorial view. K 859 (same sample as Pl. I, fig. 8).

FIGS. 2–3.—Pollen grain of the *P. connivens* type. Approximate polar view (2—high focus; 3—low focus). K 860 (same sample as Pl. I, fig. 8).

FIG. 4.—Pollen grain of the *P. connivens* type. Oblique equatorial view. K 864 from sample immediately below Yons Nab Marine Series, Gristhorpe.

FIG. 5.—Pollen grain of the *P. connivens* type. Oblique equatorial view. K 861 (same sample as Pl. I, fig. 8).

FIGS. 6–8.—Pollen grain of the *P. connivens* type. Oblique equatorial view (6—high focus; 7—middle focus; 8—low focus). K 865 from sample 20 feet above Yons Nab Marine Series, Gristhorpe.

FIG. 9.—Pollen grain of the *P. connivens* type. Polar view. K 862 (same sample as Pl. I, fig. 8).

FIG. 10.—Pollen grain of the *P. connivens* type. Polar view of distorted specimen. K 863 (same sample as Pl. I, fig. 8).

FIG. 11.—Pollen grains from araucarian male cone attributed to *Pagiophyllum connivens* Kendall. Polar view. Slide V 29561 c, Brit. Mus. (Nat. Hist.).

FIG. 12.—Another specimen from same slide as fig. 11. Slightly distorted polar view.

A *Lingula*-Bed in the Keuper of Nottinghamshire

By G. N. Rose and P. E. Kent

Abstract

Numerous specimens of *Lingula tenuissima* Bronn have been discovered in the Lower Keuper near Eakring, Notts. Earlier records of fossil bivalves in this formation are recalled and the implications of the present find discussed in relation to conditions of deposition of the Keuper.

During a visit of a party from Reading University to the Eakring oilfield in February, 1955, a stop was made to examine a small exposure of Keuper Waterstones on Stonish Hill, west of the village (Nat. Grid 43/665622). Almost the first hammer-blow dislodged a *Lingula*, the first to be found in the British Trias, and during subsequent visits with heavier tools the total has been raised to more than thirty specimens. Some of these have been deposited in the Museum of the Department of Geology at Reading (Reg. Nos. 6992–6997).

1. Locality and Horizon

The newly discovered horizon is in the lower part of the Keuper Waterstones in a 3-ft. thick bed of reddish micaceous marl. The exposure is on a line between the Bilsthorpe colliery shafts and Eakring 142 boring, and from elevations in these sinkings the level is calculated to be between 85 and 95 feet above the base of the Keuper.

The *Lingula* valves are most common in a bed immediately beneath a thin yellow band, but a few specimens have been found over a distance of 9 to 12 inches higher. The bed varies from a micaceous silty marl to a silt, and shows ripple-marked surfaces and fine cross-bedding. Occasional partings of reddish purple clay show irregular enigmatic markings (desiccation cracks ?). The majority of the *Lingula* specimens occur on micaceous partings. Some are embedded within thicker laminae and one specimen is perpendicular to the bedding and clearly in the position of growth (Text-fig. 1).

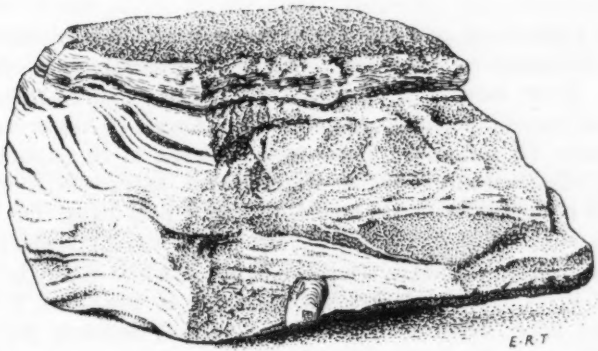
2. Identification

Miss H. M. Muir-Wood reports that " the specimens of *Lingula* are comparable both in size and shell outline to *Lingula tenuissima* Bronn (1851–2, p. 51, and pl. 13, fig. 6*b*) . . . [This species] is recorded from different horizons of the Lettenkeuper (Lower Keuper), from the *Bairdien*kalk, *Anoplophora*-Schichten, and Grenzdolomit; as well as from the Middle Keuper from the *Estheria*schichten. It is also recorded from the Muschelkalk, Wellenkalk, and Lower Hauptmuschelkalk ". From this considerable vertical range it is clear that the English speci-

mens cannot be used to correlate the level at which they occur with a German equivalent.

3. Deposition of the Keuper

The greater part of the Keuper was water-laid, with unbedded or partly bedded marls in the upper part, possibly of wind-blown origin. But opinions have varied on the exact environmental nature of deposition of the main mass. Most writers have regarded the formation as deposited in a great lake, with doubtful evidence of occasional sea connection. The deposition of extensive gypsum beds suggests the partial evaporation of large bodies of water in some way connected with, and periodically replenished by, the open sea. On the other hand, deposits of sodium chloride imply the almost total evapora-



Text-fig. 1.—*Lingula* in position of growth in current-bedded sandstone. (Reading Univ. Geol. Dept. Reg. No. 6992.) × 1.

tion of the water from salt lakes. In their lower part the Waterstones commonly contain pseudomorphs of halite which, in the absence of other minerals, is evidence of a similar kind.

4. Records of Fossils from the Keuper

Almost all the fossils from the British Keuper are plants, vertebrates, and arachnids (Herdman *et al.*, 1904, and 1908; Hull, 1869; Wills, 1910; Wills and Campbell Smith, 1913), and the beautifully preserved fish discovered and described by Swinnerton (1925, 1928) were from a locality 20 miles south of Eakring. However, the latter are not types diagnostic of depositional conditions.

Estheria (*Euestheria*) *minuta* is not uncommon at certain localities in the Central Midlands, and lamellibranchs variously called *Mytilus* (?) *sphinx* (Wills, 1910, pp. 301–2) or ?*Modiola* (Wills, 1935, p. 241) are reported from shaly bands in the Waterstones of Worcestershire.

Wills (1910, p. 302; 1929, p. 107; 1948, p. 85) did not consider these mollusca provided satisfactory evidence of marine conditions, and regarded the Lower Keuper as deposited in a freshwater or only slightly saline lake. Later, he commented (1951, p. 41) that the fossil evidence was conflicting. R. L. Sherlock (1948, p. 48) also regarded the evidence as of doubtful value, although Gregory and Barrett (1931, p. 142) and Stamp (1934, p. 201) envisaged the possibility of a minor transgression of the Muschelkalk Sea.

Dr. C. L. Forbes has examined the specimens of *Mytilus* (?) *sphinx* (Sedgwick Museum, figured specimen G. 283, and other specimens from the same horizon and locality G. 284–295), and reports " the umbo is in all cases terminal as in *Mytilus* or *Dreissena* [*Dreissensia* auct.] rather than sub-terminal as in *Modiola*, but otherwise neither Mr. Brighton nor I wish to express an opinion more decidedly than Wills ".

At a higher level possible marine forms were recorded from the Arden Sandstone of Shrewley Common, Warwickshire, by Brodie (1894). From these R. B. Newton (1893, 1894) identified three new species of lamellibranch, *Thracia* (?) *brodiei*, *Nucula* (?) *keuperina*, and *Pholodomya* (?) *richardsi*. These he considered to be undoubtedly marine. Hence on this and other evidence C. A. Matley (1912, pp. 268 and 276) postulated a marine interlude in the Upper Trias. Dr. L. R. Cox has expressed the following opinion on *Thracia* (?) *brodiei* (holotype, Brit. Mus., L. 9717), *Pholodomya* (?) *richardsi* (syntype, Brit. Mus., L. 9718), and *Nucula* (?) *keuperina* (syntypes, Brit. Mus., L. 9719 and Geol. Surv., 4979): " It is impossible to say definitely that they are marine, notwithstanding the genera to which Newton tentatively referred them."

5. Discussion

Hitherto, indications of temporary marine or near-marine conditions in the Keuper have rested on very slender evidence and the discovery of *Lingula* is of importance, not only in showing a salinity approaching that of sea water, but also in proving a temporary connection with the seaways of Europe. Modern species of *Lingula* are essentially marine animals, inhabiting the sand or mud of shallow tropical and subtropical seas. Sometimes the habitat is above low tide-mark in inlets or estuaries and at least one species lives in an almost totally enclosed sea (Craig, 1952, pp. 113 and 115). This variety of habitat implies some tolerance of varying salinity, but the limits are not accurately known and no freshwater species have been reported.

Dr. C. J. Stubblefield commented on the remarkable resemblance between the *Lingula*-bed at Eakring and those of the Downtonian (Elles and Slater, 1906). The Downtonian basin, like that of the Keuper,

is regarded as set in a landscape which supplied red detritus, and Wills (1951, p. 19) described it as " a marine delta that was occasionally flooded by the sea, and at other times by temporary lakes and rivers ". The Keuper deposits are less like those of a delta than of a broad lake frequently drying to disconnected pools. At times the water in this lake may have varied from fresh at one end to almost marine at the other. The connection with the sea could have been either in the south-west (a forerunner of the Rhaetic sea ?) or in the east with the Muschelkalk Sea of Germany. The discovery of *Lingula* at Eakring favours the easterly connection and the area might be considered to have been near the end of one of a series of marine fingers coalescing eastwards to a fully marine succession.

The sandy Lower Keuper is a poor custodian of calcareous fossils, and the survivors so far discovered may be only a token of the variety and abundance of life at the time. However, they emphasize the importance of searching the more marly parts of the Keuper Waterstones in other places whenever the opportunity occurs.

6. Acknowledgments

The authors wish to thank Dr. H. M. Muir-Wood for her report on the specimens of *Lingula* and Drs. C. L. Forbes and L. R. Cox for their opinions on the lamellibranchs.

They are also indebted to Miss E. R. Turlington for the drawing reproduced as Text-fig. 1 and to Dr. F. Hodson for helpful advice.

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A Probable Organic Structure from the Dalradian of Ben Vrackie, Perthshire

(PLATE XXII)

By H. M. Pantin

Abstract

Globular bodies, which may represent organic remains, are found in the Dalradian at a locality on the south-west side of Ben Vrackie. Their mode of occurrence, composition, and form are here described and their possible affinities are discussed.

Introduction

THE structures to be described occur in a Dalradian hornfels intervening between the epidiorite of Ben Vrackie and the near-by Ben Eagach Schist at a locality (National Grid reference 947628) on the south-western side of the hill. Although the rocks of the surrounding district are nearly all highly deformed and regionally metamorphosed, remnants of thermally metamorphosed rocks are found locally at the epidiorite contacts (Barrow, et al., 1905, pp. 77 et seq.). These contact rocks have, in varying degrees, resisted deformation, and the structures owe their preservation to this.

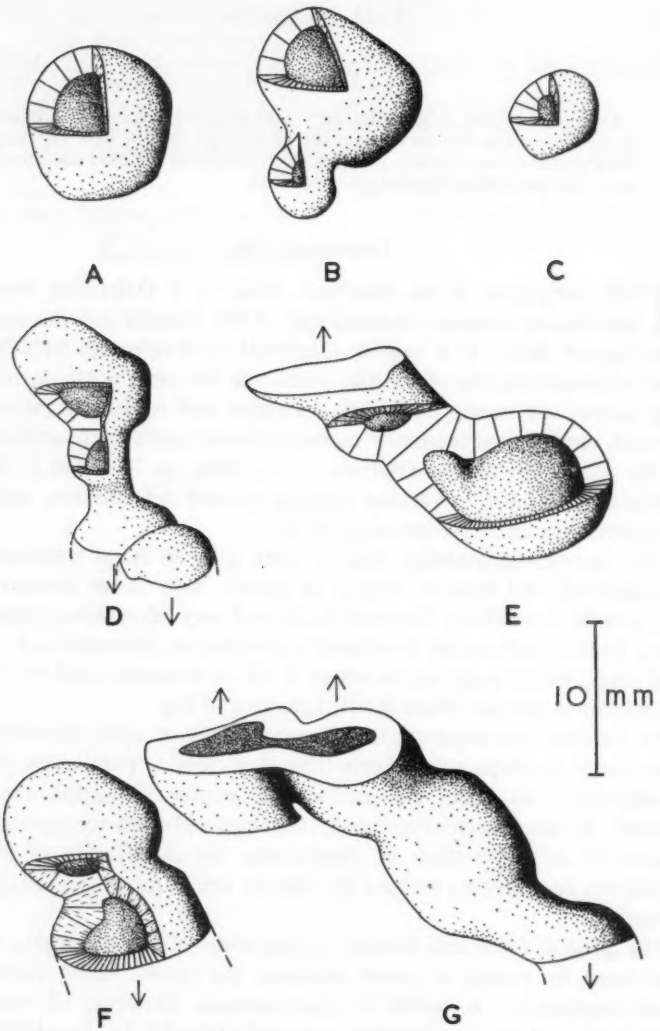
The hornfels containing them is dark grey in hand specimen, is fine-grained, and consists largely of quartz, with minor amounts of clinozoisite, hornblende (as small rods), and very fine-grained graphite. On a broken surface the structures are visible as light-coloured spots and rings, which range up to about 1 cm. in diameter, and are often associated in groups (Plate XXII, figs. 1a and 1b).

In the field the structure shows many stages of later deformation. The matrix develops a schistosity (due to increasing parallelism of the hornblende rods), and the individuals become elongated and ill-defined. In the most deformed rocks the rings and spots are represented merely by diffuse patches of clinozoisite, the significance of which would not be suspected without the near-by occurrence of less distorted examples.

The general form and mutual arrangement of the structures were elucidated by means of serial sections, the results being recorded photographically. A series of diagrammatic drawings of various individuals and groups was then prepared (Text-fig. 1). In addition a direct reconstruction of the bodies encountered during serial-sectioning (Plate XXII, fig. 2) was made by stacking plate negatives of the recorded surfaces in methyl benzoate ($n = 1{\cdot}52$).

Description

The structures are basically spheroidal or ellipsoidal in shape and range up to about 1 cm. in diameter, the majority being 7 mm. to 10 mm. in width. Each possesses a dark inner core, with a diameter



Text-fig. 1.—Idealized drawings of various individuals, showing the relationship between the dark core and the enclosing light-coloured zone (the radial ornament is diagrammatic). Different types of mutual arrangements are also illustrated.

varying from one-third to three-quarters of the whole, surrounded by a light-coloured outer zone. Both zones consist of clinozoisite, the crystallographic orientation of which appears to bear no relationship to the form of the individuals or to their internal structure. The clinozoisite forming the dark inner zone is fine grained, and is accompanied by an appreciable proportion of very fine-grained graphite. In the outer zone the clinozoisite is moderately coarse in grain, and a little calcite may be associated with it. Thin sections also demonstrate that the outer zone is itself enclosed by a narrow peripheral zone (about $\frac{1}{2}$ mm. in width) which is composed of material very similar to the inner zone, although a little hornblende and/or quartz may be present. This peripheral zone, however, is not usually visible in hand specimen.

In bulk the structures tend to form complex, elongated aggregates in which adjacent bodies show three main types of mutual arrangement. Individuals may be joined peripherally (Text-fig. 1, B. D, F), incomplete individuals may pass into one another (Text-fig. 1, E, G), and individuals a little distance apart may be joined by short connections (Text-fig. 1, D, lower part, and G, bottom right). The latter are composed of material similar to the light-coloured outer zones, and each is surrounded by a dark fine-grained peripheral zone. These connections may attain a length of 6–7 mm. and possess a circular or elliptical cross-section, their mean diameter ranging from about 2 mm. up to 6 mm. or over.

In the great majority of individuals the outer zone contains small columnar, tabular, and equant bodies consisting of material similar to the inner zone. On a polished surface these bodies are visible as dark bands and spots (Text-fig. 2). The columnar varieties, which are the most abundant, may reach a length of 1·5 mm.; they may be circular or elliptical in cross-section, with a mean diameter ranging from 0·02 mm. up to 1 mm. or over. A radial disposition is characteristic, but oblique and concentric examples also occur, and may show branching and interconnection. The longer columns often reach the inner zone, the peripheral zone, or both. The tabular and equant bodies, whose width ranges up to about 0·6 mm. and 0·4 mm. respectively, are distributed among the columnar structures, and are sometimes connected to the latter.

Larger, but more irregular, dark bodies also occur in the outer zone, and may occupy considerable segments of the latter. Frequently, over much of their extent, they are continuous with the inner zone and/or the peripheral zone. Their maximum width is about 3–4 mm.

In a few individuals the inner zone contains radially directed columnar bodies, projecting from the outer zone and consisting of material similar to the latter. Their length may reach 1·5 mm. and they

are circular or elliptical in cross section with a mean diameter lying between 0·05 mm. and 0·2 mm. These columnar projections are visible on a polished surface as light-coloured bands and dots (Text-fig. 2).

TEXT-FIG. 2.—Typical cross-sections (partly diagrammatic) showing the dark inner zone and the light-coloured outer zone. In both *a* and *b* the outer zone contains the characteristic dark bands and spots ; light-coloured bands are visible in the inner zone of *a*.

ORIGIN AND AFFINITIES

It seems probable that the structures under discussion are organic in origin. Their regular size and form, their mutual arrangement, and their internal detail show clearly that they cannot have arisen as a consequence of thermal or regional metamorphism. The latter process, indeed, tends to destroy them. Furthermore, their characteristics are not those of inorganic sedimentary concretions.

The preservation of the structures in calc-silicate suggests that they were rich in primary or secondary calcium carbonate, and it is likely that the test of the living organism was composed of calcite or aragonite. The inner and outer zones now found are taken to correspond to concentric zones present in the original test, differing in composition or texture. The outer zone probably represents a fairly massive part of the test. The inner zone, on the other hand, may represent a porous part of the test or a cavity within it. No structure resembling a well-definied osculum has been found.

The occurrence of graphite in the rock indicates the former presence of organic material, which may have been derived from the organism itself. Hœg (1927) recorded examples of the calcareous alga *Dimorphosiphon* containing dark material with a distribution very similar to that of the graphite in the various zones of the present structures.

There appears to be no organism on record that bears a close resemblance to these structures. However, many of their features find a parallel in different calcareous algae. The tests of the codiaceous genera *Dimorphosiphon* Hœg and *Paleoporella* Stolley show a bizonal arrangement, the outer zone being more massive and containing a larger proportion of calcite than the porous inner zone. A similar feature might account for the difference between the outer and inner zones of the

structures under discussion. The wall-structure of the latter, moreover, is not unlike that found in the two Codiaceae.

Certain dasycladaceous algae, such as the solitary *Coelosphaeridium* Romer and *Cyclocrinus* Eichwald, and the colonial *Mizzia* Schubert, possess globular tests whose form is rather similar to that of the more isolated individuals among the structures here considered.

The following extracts from personal communications on this matter are quoted by kind permission of the authorities concerned. From Professor B. F. Howell, of Princeton : " The objects which you have found in your Dalradian rocks certainly look as though they were of organic origin. They have may been sponges, but I know of no Early Palaeozoic calcareous sponges that resemble them in form. . . . The other most probable explanation of the nature of these objects is that they may be fossils of calcareous algae."

From Professor J. Harlan Johnson, of the Colorado School of Mines: "Judging merely by the general appearance, the size, and the shape, the objects could represent members of the algal genus *Paleoporella*."

Although Pringle (1939) found Middle Cambrian trilobites in the Leny Limestone, which is considered by some authors to belong to the Dalradian series, there appears to be no record of organic remains from rocks certainly within the Dalradian succession.

ACKNOWLEDGMENTS

The writer wishes to record his indebtedness to Professor J. Harlan Johnson, of the Colorado School of Mines, Professor B. F. Howell, of Princeton University, Professor L. Størmer, of the Oslo Paleontological Institute, Professor J. Walton, of Glasgow, and Dr. R. H. Cummings, of Glasgow, for their opinions regarding the possible nature of the structures. He also wishes to thank Professor A. Williams, of Belfast, for advice regarding the techniques used during the investigation, and Dr. C. F. A. Pantin, of Cambridge, with whose help the photographic reconstruction was made. Finally, he would like to thank Dr. R. H. Cummings, Dr. B. C. King, and Professor T. Neville George for reading the manuscript and for many helpful suggestions and criticisms.

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EXPLANATION OF PLATE XXII

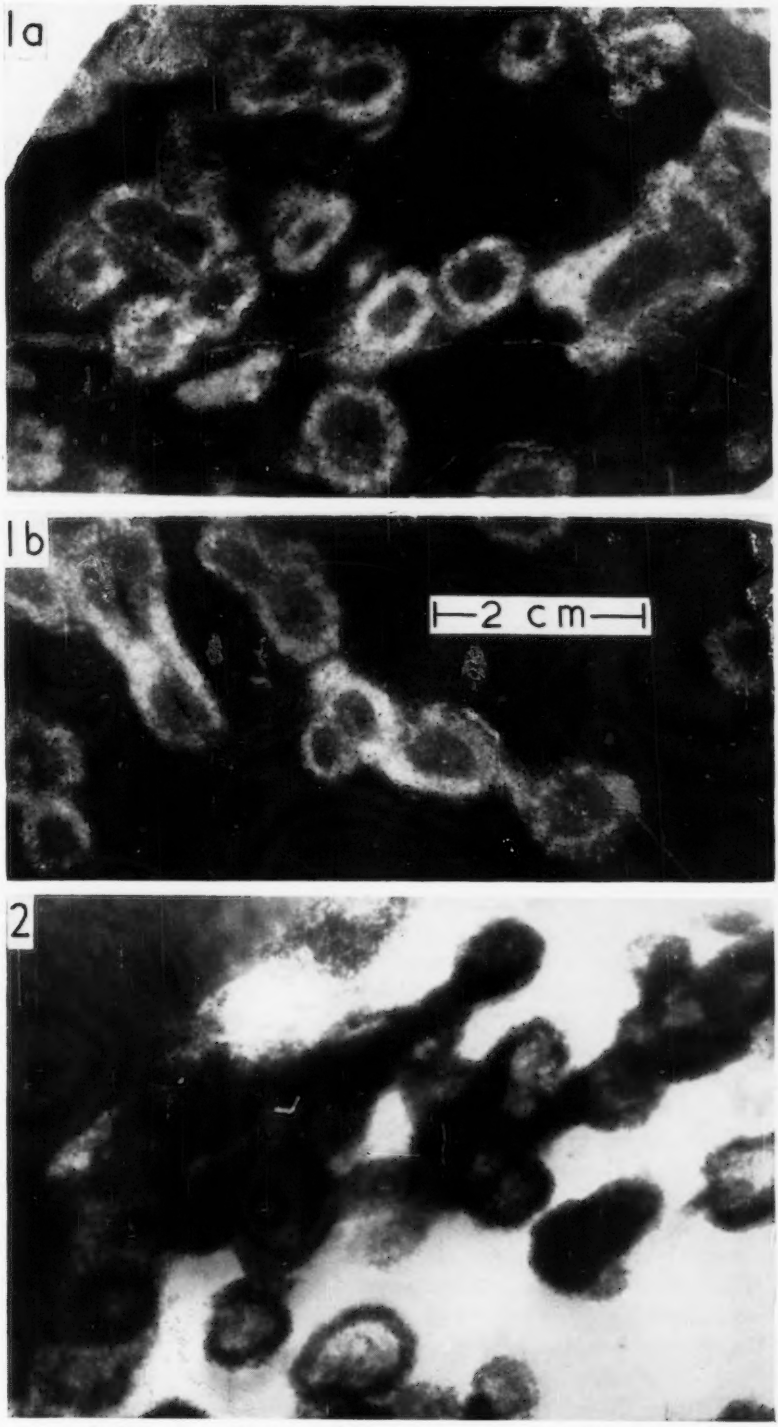
FIG. 1a.—The original polished surface of the specimen used for reconstructing the form of the individuals.

FIG. 1b.—The main reference surface of the same specimen.

The above surfaces intersect at an angle of 77° (measured through the rock), and the edge of intersection forms the lower border of Fig. 1a and the upper border of 1b.

FIG. 2.—Photograph of the direct reconstruction, using stacked plates. The faint shadows visible below some of the structures are due to oblique illumination from above.

All three figures are approximately the same scale.



A PROBABLE ORGANIC STRUCTURE FROM THE DALRADIAN.

The Geology of the Islands of South Connemara

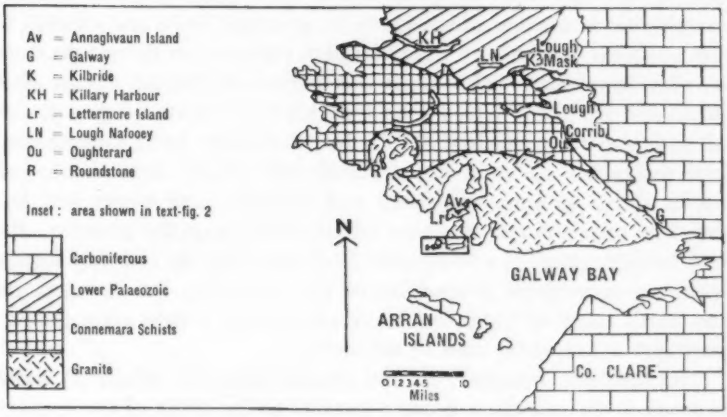
By Duncan McKie and Kevin Burke

Abstract

The exposed part of the metamorphic envelope on the south side of the Galway granite is described. It is characterized by the presence of pillow lavas and a thick greywacke series containing intraformational conglomerates. This South Connemara Series is tentatively assigned to the Ordovician; such a correlation would require the Galway granite to be a Taconic intrusion.

Introduction

THE district described in this paper on the islands of Gorumna, Lettermullen, and Crappagh in Galway Bay, due north of the



Text-fig. 1.—Locality Sketch-map.

Aran Islands (Text-figs. 1 and 2), comprises the outcrop of the only part of the southern margin and metamorphic envelope of the Galway granite not obscured by the sea. Because of the interest attaching to the recognition of marked contrast between the northern and southern margins of the Galway granite, and to the finding of a series including conglomerates and pillow lavas of possibly Ordovician age in the southern aureole, an account of this area is being presented separately from the more extensive study of the Galway granite and its envelope on which one of us has been engaged for several years (partly in Burke, 1953).

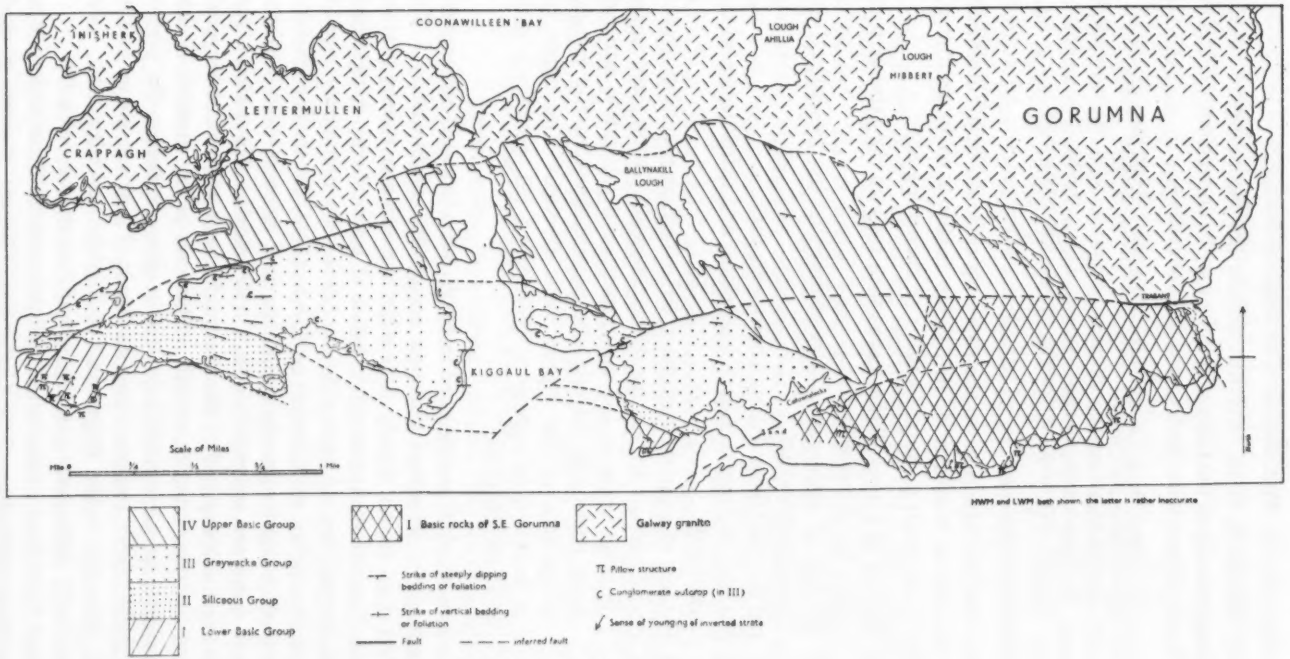
The islands do not appear to have been visited by geologists since the officers of the Geological Survey of Ireland made their rapid 6-in. survey in the 1860's (Kinahan, *et al.*, 1871), until the authors spent four weeks there in the summer of 1954. Access to the islands is

provided by the main coast road from Galway which, passing over viaducts and swing-bridges, crosses the islands in turn; there is an hotel on Annaghvaun (between Gorumna and the mainland), and an An Oige hostel on Gorumna. The rock exposure is very good on the broad wave-cut platforms of the much indented coast; the granite outcrop is often almost a desert of bare rock and the metamorphics, although supporting some agriculture, are well displayed in frequent large *roches moutonnées.*

The Granite

In the north the Galway granite makes a concordant migmatitic junction with its basic envelope (Burke, 1953), grading southward into a strongly foliated granodiorite and then into the coarsely porphyritic adamellite which forms its principal facies and extends to the southern margin with little variation except a southward decrease in phenocryst size. This facies has subhedral phenocrysts of pink alkali-feldspar from ½ to 1 inch long set in a matrix of plagioclase, alkali-feldspar, quartz, and biotite, the plagioclase being saussuritized and the biotite to some extent chloritized. Many small bodies of aplite and pegmatite, associated and separate, and larger but less frequent quartz-porphyry dykes occur throughout the granite; the two former represent a very small total bulk, but the last may locally form an appreciable proportion of the intrusion, for instance, on the north shore of Crappagh there are in half a mile eight quartz-porphyry dykes, more than 10 feet wide.

The southern boundary of the granite, over the whole 5½ miles exposed in the islands, is broadly parallel to the strike of the country rocks, but is clearly cross-cutting in detail. The embayments in the centres of Lettermullen and Gorumna and particularly the ½ mile long tongue of granite north-west of Trabane may be evidence of magmatic stoping. Xenoliths are not abundant near the contact, except in Crappagh, where two large disoriented xenoliths are shown to scale on the map (Text-fig. 2). The porphyritic adamellite is, as Cruise observed (Kinahan, *et al.*, 1871, p. 51) in some places separated from the country rocks by a selvedge, about 2 inches wide, of a fine-grained, rather quartz-rich, granitic facies, which may perhaps be tentatively interpreted as a chilled margin. An apparently identical rock occurs in dykes cutting porphyritic adamellite, chilled-margin, and country rock; the dykes themselves are cut by later quartz-porphyries. Reaction with the country rocks is restricted to within a few yards of the granite margin; quartzites have recrystallized with increased grain-size and the introduction of an abundant feldspathic matrix, and biotite porphyroblasts have grown in amphibolites.


COONAWILLEEN BAY
INISHERK
LETTERMULLEN
CRAPPAGH
LOUGH AHILLIA
LOUGH HIBBERT
GORUMNA
BALLYNAKILL LOUGH
KIGGAUL BAY
Scale of Miles
Mile 0
1/2
1
1 1/2
1 Mile
IV Upper Basic Group
III Greywacke Group
II Siliceous Group
I Lower Basic Group
I Basic rocks of S.E. Gorumna
Galway granite
Strike of steeply dipping bedding or foliation
Strike of vertical bedding or foliation
Fault
inferred fault
Pillow structure
Conglomerate outcrop (in III)
Sense of younging of inverted strata
HWM and LWM both shown, the latter is rather inaccurate

TEXT-FIG. 2.

The South Connemara Series

The sediments, lavas, and sills within the metamorphic envelope on the south side of the Galway granite may be conveniently designated the South Connemara Series, and subdivided:—

(iv) Upper Basic Group	max. thickness:	5,000	feet
(iii) Greywacke Group	,, ,,	2,500	,,
(ii) Siliceous Group	,, ,,	900	,,
(i) Lower Basic Group	,, ,,	1,500	,,

(i*) Of uncertain correlation, in S.E. Gorumna only.

(i) *Lower Basic Group.*

The excellent exposure on the rocky tip of south-west Lettermullen and the diverse character of this group enable it to be further subdivided from south to north in order of decreasing age:—

(1) 300 feet of Lower Pillow Lavas with tuffs on the extreme south-west tip of Lettermullen.

(2) 100 feet of calcareous shales represented by fine-grained calc-hornblende-schist.

(3) 160 feet of Upper Pillow Lavas with tuffs.

(4) 200 feet of impure quartzites, pelites, and a few lenses of conglomerate.

(5) 700 feet of amphibolites characterized by cross-cutting relations with respect to the overlying Siliceous Group, rare garnet-diopside veins in the upper part, and no pillow structure; these rocks are scarcely distinguishable from the principal component of the Upper Basic Group. The upper part at least would appear to represent a sill, perhaps a rather shallow intrusion.

The pillows of (1) and (3) are 6 inches to 6 feet long and preferentially elongated in a direction plunging about 30° south-easterly. Fine-grained skins are not clearly discernible but vesicular texture is always obvious, two or three concentric bands of vesicles often lying parallel to the curved top of each pillow. Pillows are commonly moulded one on to another, the criterion of Wilson (1911) for the determination of attitude being frequently applicable, and in every case consistent. Hollow cores are recognizable in a few pillows. The pillows themselves are now composed of chlorite and feldspar with calcite amygdales fringed by larger chlorite crystals. The inter-pillow material is either pink marble or a quartz-feldspar-zoisite-garnet-sphene-rock, presumably derived from a calcareous grit. Bands of pink marble up to 3 feet thick, crowded with fragments of highly vesicular lava, occur sporadically, commonly grading into slightly calcareous tuffs.

Apart from their characteristic pillow structure these rocks are not unlike the amphibolites of the Upper Basic Group; they are markedly

calcareous, in the coarser types large hornblende crystals occur and moreover patches of garnet and diopside occur in the pillow lava divisions.

(ii) *Siliceous Group.*

Principally impure quartzites with occasional thin feldspathic and pelitic partings. Thin, regular, usually graded bedding and the dead-whiteness of weathered surfaces are characteristic features, especially well displayed along the south-east coast of Lettermullen. Passage to the overlying greywackes is effected by increase in feldspar and mica content and in grain size.

(iii) *Greywacke Group.*

The limits of the group are determined by the rapid change from the quartzites at the base and by the first appearance of amphibolites at the top. The dominant rock type is composed of angular quartz and microcline-microperthite in a groundmass of quartz, cloudy plagioclase, biotite, and muscovite with accessory sphene and tourmaline; the mica grains tend to be wrapped around the larger quartz and feldspar grains; in markedly pelitic bands cordierite occurs (mostly pinite relicts); intergranular chlorite is common. The feldspar is unevenly distributed so that lenticular patches crammed with large feldspar fragments are interspersed with finer-grained less feldspathic material. The general composition and poor sorting suggest a metamorphosed greywacke. Three important variants occur:—

(1) Greywacke with very uniform graded bedding, which appears " metamorphically reversed " (Read, 1936) in outcrops nearer the granite, due to the development of porphyroblastic cordierite producing an apparent coarseness of grain in the pelitic part of each bed.

(2) Pelitic bands some 6 inches thick composed of well oriented biotite and muscovite, quartz, and porphyroblastic cordierite.

(3) Conglomerate lenses usually about 10 feet thick and 10 to 20 yards long, passing into greywacke. The conglomerate constitutes about 50 per cent of the Group in the west and becomes less abundant eastwards; conglomerate has nowhere been found in the bottom 200 feet. The boulders are mostly of quartzite, with some of granite, granodiorite, quartz-porphyry, and slate, all are well rounded except the slate and usually less than 1 foot long. The matrix is similar to the coarser varieties of greywacke and merely fills the interstices between boulders that are in contact. In a few localities, however, boulders have been found scattered in greywacke.

(iv) *Upper Basic Group.*

This Group consists of amphibolites with characteristically oblate lenses of green diopside and brown garnet (Nd = 1·736, nearly pure grossularite), interspersed with quartzite horizons now lenticular in outcrop. The amphibolites are usually fine-grained, but occasionally contain hornblende crystals up to ¼ inch long. The hornblendes show no conspicuous preferred orientation, but a well defined, coarse, somewhat irregular foliation is imparted to the rocks by the garnet-diopside lenses. These lenses vary greatly in size averaging about 4 × 4 × 1 inch, they reach a maximum dimension of more than 1 foot. The lenses and the less common veins usually consist of an outer zone of diopside and an inner zone of garnet, the smallest examples containing only diopside. Calcite occurs in the larger lenses as an innermost zone or dispersed irregularly through the garnet. At the margins of the veins and lenses there is a transition from the hornblende-plagioclase-quartz assemblage of the amphibolite through an intermediate zone of granular diopside—plagioclase and quartz to a zone of large clear pale diopside and cloudy plagioclase at the vein border. The vein proper contains garnet-diopside-epidote and calcite sometimes with large plagioclase crystals or smaller groups of sericite flakes. The field appearance, of the veins in particular, is suggestive of a replacement origin; thus, where two veins intersect, their diopside sheaths coalesce and broaden to form an irregular patch about the junction. However, the data are consistent with the metamorphism of a basic lava and calcareous sediment complex, such as that of the Lower Basic Group; the calcitic parts would provide a source of abundant CO_2 which would promote metamorphic diffusion and might give rise to the small networks of replacement veins. The lenses and veins altogether constitute about 5 per cent of the total bulk of the Upper Basic Group amphibolites, and are uniformly distributed over the whole outcrop, not favouring particularly any horizon nor the vicinity of the granite.

Siliceous bands composed essentially of quartz and alkali-feldspar occur fairly frequently, especially on Gorumna. They vary from a few to several hundred feet in thickness, and usually wedge out along the strike after a few hundred yards.

(i*) *Basic Group of S.E. Gorumna.*

It is uncertain whether these rocks should be identified with (i) or with (iv), since their junction with (iv) is the location of shatter-belts interpreted as tear-faults. If the faults are sinistral, as are other tear-faults of similar strike recognized in the islands, identification with (i) is favoured; moreover (i*) contains excellently preserved pillow-structure, unknown in (iv). However, the presence of extensive

siliceous bands and garnet diopside lenses in (i*) suggests a correlation with (iv); in that case the displacement along the faults would be smaller though dextral. In view of the proximity of the granite and the notoriously sporadic occurrence of recognizable pillow-structure in piles of pillow lavas the balance of evidence is considered to be inconclusive.

Structure

Murphy's (1952) gravity survey revealed a low Bouger anomaly on the south coast of Galway Bay, which he interpreted as due to a southward extension of the Galway granite below the Carboniferous right across Galway Bay to the Co. Clare coast. Little light is thrown on this hypothesis by our examination of the South Connemara Series; our impression in the field was that we were observing the actual southern margin of the granite but we know of no evidence that shows that the rocks could not be a roof-pendant. It is hoped that further gravity observations may be made on the Clare coast and especially on the Aran Islands.

The strike of the foliation in the South Connemara Series is east in Crappagh and W. Lettermullen, changing to east-south-east over the rest of Lettermullen and Gorumna and swinging round to south of south-east near Trabane in the extreme east of Gorumna. The dip of the foliation is always steep southwards or vertical. Bedding, where determinable in the metasediments, is in general parallel to the foliation; however, in the Siliceous Group exposures along the south coast of Lettermullen the bedding is seen to lie here and there in small folds with axial planes parallel to the foliation. Attitude is determinable (1) in the pillow lavas of the Lower Basic Group and of (i*) by application of the criterion proposed by Wilson (1911), that is, pillows sag into the V-shaped cavity between the upper surfaces of those on which they lie; (2) in the Siliceous and Greywacke Groups in Lettermullen where graded bedding is well displayed; (3) in the Graywacke Group nearer the granite in which metamorphically reversed graded bedding (Read, 1936) has been recognized. The Upper Basic Group contains no attitude-determining structures. In every determinable case younging is to the north, that is, the South Connemara Series dips steeply southward with inversion.

There are no apparent major fold structures. Minor folds are recognizable sporadically in the Greywacke and Siliceous Groups; axes pitch generally westward.

There is no evidence that the formation boundaries are surfaces of significant movement, therefore the sequence (i) to (iv) may be interpreted as a stratigraphical succession.

Faults have been inferred as follows:—

(1) Sinistral tear-fault striking N.E. along a gully in south-west Lettermullen, then E.N.E. up the inlet, and along the granite margin; the (i)/(ii) boundary is thrown $\frac{1}{8}$ mile and (ii)/(iii) $\frac{1}{4}$.

(2) Sinistral tear-fault to explain the $\frac{1}{2}$ mile throw of the (ii)/(iii) boundary across Kiggaul Bay; this possibly coincides with the marked topographical feature along the (iii)/(iv) boundary where that is deflected into an E.N.E. alignment, and may then follow the E.-striking depression and shatter-belt to become the Trabane fault.

(3) Tear-fault parallel to the Callownalecka shatter-belt to explain the throw of the (iii)/(iv) boundary across the shatter-belt. The eastward continuation of this fault is uncertain; it is possibly related to the Trabane fault by a series of fractures *en echelon.*

(4) Sinistral tear-fault, the Trabane fault, which throws the granite margin 150 yards along the harbour inlet, and then runs westwards in a broad shatter-belt along the (i*)/(iv) boundary.

The tear-faulting here appears to postdate, at least in part, the Galway granite intrusion.

Age Considerations

Wager and Andrew (1930) called the rocks of the medium and high grade metamorphic tract on the north side of the Galway granite the Connemara Schists and discussed the age of their metamorphism in the light of the following facts: (1) their junction with fossiliferous Arenig rocks is always complicated by faulting or intrusion; (2) they are overlain unconformably by fossiliferous Wenlockian (Owenduff Series) at several localities to the S.W. of the entrance to Killary Harbour; (3) at these localities the Wenlockian basal conglomerate contains chlorite and clastic micas in its matrix whereas the Connemara Schists are represented by biotite-schists and garnet-mica-schists; (4) cleavage and minor folding are similar above and below the unconformity. From these data it is clear that the Connemara schists were regionally metamorphosed in pre-Wenlockian times and later subjected to Caledonian stresses which may have generated their ubiquitous diaphthoretic chlorite. Callaway (1887) and Carruthers and Maufe (1909) regarded the Connemara Schist metamorphism as Pre-Cambrian. Kilroe (1907), however, having noticed the absence of the Valentian at Lough Nafooey, considered that the Wenlockian overstep might correspond to this intra-Lower Palaeozoic unconformity and that the Connemara Schists might be Lower Palaeozoic rocks. Gardiner and Reynolds (1909, 1911, 1912, 1914) confirmed the existence of such an unconformity as a regional feature, but placed it in the Upper

Valentian. Wager and Andrew (1930) reviewed the evidence, stressing the importance of the metamorphic break and the unlikelihood of a pre-Wenlockian Lower Palaeozoic regional metamorphism here; they concluded, therefore, that the Connemara Schist metamorphism was Pre-Cambrian. Wager (1932) and Mrs. Ingold (1938) have both discussed the history of the Connemara Schists, it is sufficient to state here that the schists contain a record of numerous plutonic events, probably representing more than one orogenic period. The intrusion of the Galway granite took place at a late stage in this series of events.

An upper age limit for the Galway granite is provided by the presence of Valentian fossiliferous shales at Curraghevagh, near Oughterard.[1] These rocks overlie and are not metamorphosed by the Oughterard Granite intrusions (Burke, 1953), which postdate the main Galway Granite emplacement. Therefore, the Galway Granite intrusion and, consequently, the regional metamorphism are pre-Valentian. If the main Galway granite is a single intrusion, as would appear from the observations so far made in spite of its contrasting northern and southern margins, then the South Connemara Series must be pre-Valentian. If the granite is a composite intrusion, then its parts were probably emplaced in the course of the same orogeny, and moreover as considerable erosion of the northern marginal facies had taken place by Valentian times, it would seem probable that the South Connemara Series would in this case also be pre-Valentian.

The low degree of deformation, evidenced particularly by the excellent preservation of sedimentary and pillow structures, suggests that the South Connemara Series is unlikely to be Pre-Cambrian; it would thus appear to belong to some part of the Cambrian or Ordovician. The Cambrian is nowhere exposed in West Central Ireland, but elsewhere in Britain it contains no volcanics.

The Ordovician, however, outcrops in northern Connemara 30 miles from the Islands in the core of a broad anticline running east from Killary Harbour through Lough Nafooey and Kilbride. It has been described by Kilroe (1807), Carruthers, and Maufe (1909), Gardiner and Reynolds (1909, 1911, 1912, 1914), and more recently by Harper (1948) and Theocritoff (1951). At Lough Nafooey and Kilbride Gardiner and Reynolds (1912, 1914) found Arenig tuffs and spilites of rapidly varying thickness associated with graptolitic shales of the *extensus* zone and overlain by a thick series of Llandeilo greywackes, the Mweelrea Grits, with intraformational conglomerates, the whole representing a typical geosynclinal near-shore facies. One of us (K. C. B.) has been able to pay a brief visit to Lough Nafooey. The Mweelrea grits at that locality bear a striking resemblance to the

[1] Personal communication from R. Bradshaw, University College, London.

clastic sediments in the islands. They contain lenticles of conglomerates, of similar dimensions to those described above, with fragments of quartzite, granite, and quartz porphyry, these fragments are comparable in size and roundness to those on the islands. There are rocks, termed limestone breccias by Gardiner and Reynolds, whose occurrence within the volcanic series at Lough Nafooey is reminiscent of the marbles in the Lower Basic group on Lettermullen. Since the Arenig rocks are the only known pillow lavas in the Irish Ordovician and in view of the general similarity of the whole series a tentative correlation may be made between the L. Nafooey spilites and the L. Basic Group (i) and between the Mweelrea Grits and the Siliceous and Greywacke Groups (ii), (iii), with the U. Basic Group outstanding as a peculiarity of the succession in the islands; that is a tentative identification of the South Connemara Series with part of the Arenig to Llandeilo stages of the Ordovician. Such a correlation would necessitate assigning the emplacement of the Galway granite to late Ordovician or very early Silurian times, that is to the period of the Taconic movements, which have so far in the British Isles been identified only with a widespread sub-Valentian unconformity of varying magnitude and rather minor granitic intrusions in North Wales. It would thus appear possible that in Connemara the Taconic orogeny is represented by the latest progressive events in the regional metamorphism of the Connemara Schists and the emplacement of the Galway granite which would then be contemporary with the Highlandcroft Magma Series of New England.

In the Killary Harbour district the Rosroe Grits and the Owenduff Series contain evidence of a shoreline to the south in Arenig and Wenlock times respectively (McLaren and Miller, 1948). The Wenlock case would be satisfied by the present hypothesis or by the assumption of a Pre-Cambrian age for the regional metamorphism and Galway granite emplacement, but the Arenig case offers some difficulties if a Taconic age is assumed. The direction of derivation of the sediments of the South Connemara Series has not been determined but it is clear that there was a shoreline near by. No indication of the age of the Connemara Schist deposition has been obtained, except that it is pre-Valentian; moreover, the possibility of multiple regional metamorphism of the Connemara schists with the earlier stages of Pre-Cambrian age must be considered. If, as seems likely, such is the case, a land-mass might well have existed in north Connemara right through Lower Palaeozoic times and provided a southerly source for the Rosroe Grits and the Owenduff Series and a northerly source for the South Connemara Series sediments.

In north Connemara the Taconic movements are represented by a pronounced sub-Valentian unconformity so that Silurian with basal

conglomerate rests on either Mweelrea Grits or Connemara Schists; the Caradocian and Ashgillian are apparently absent.

The ultimate weakness of lithological correlations cannot be over-emphasized, but we would feel reluctant to assign the rocks of the South Connemara Series to the Pre-Cambrian on the basis of lithological analogy to any Pre-Cambrian rocks in the British Isles. We consider that we have evidence that is at least suggestive of a Taconic age for the Galway granite intrusion.

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The Occurrence and Significance of Pre-Cambrian Algal Forms at Kabwer Hill, Bukoba District, Tanganyika, and in Singo, Uganda [1]

By J. W. PALLISTER

(PLATE XXIII)

ABSTRACT

Stromatolites found in Karagwe-Ankolean rocks on the Tanganyika–Uganda border occur in siliceous beds associated with cherty and ferruginous breccia without trace of calcareous material. Somewhat similar conditions prevail in beds of the Singo Series of Uganda from which *Collenia*-type structures have been recorded. Little stratigraphical value can be ascribed to the structures, but they are significant in pointing to the replacement character of some fine-grained siliceous beds which may explain the scarcity of limestone in the Pre-Cambrian sequence of Uganda.

LOCALITY

KABWER (Kabuer) Hill is situated in the lower Kagera Valley, Lat. 1° 11′ S., Long. 31° 05½′ E., and lies between the Nsongezi–Nyakanyasi–Kyaka road and the Kagera River. It belongs to a chain of hills which extends from the Uganda–Tanganyika border south-south-eastwards for at least 30 miles and which in the northern part forms the east side of the broad Kagera Valley. Near Kabwer, the Kagera is deflected from its south-easterly course, breaches the barrier of hills, and emerges on to the broad, flat, lacustrine plain which extends to its mouth on Lake Victoria. Kabwer Hill is about half a mile long in a north–south direction and rises abruptly from the alluvial plain to a height of about 230 feet.

GENERAL GEOLOGY

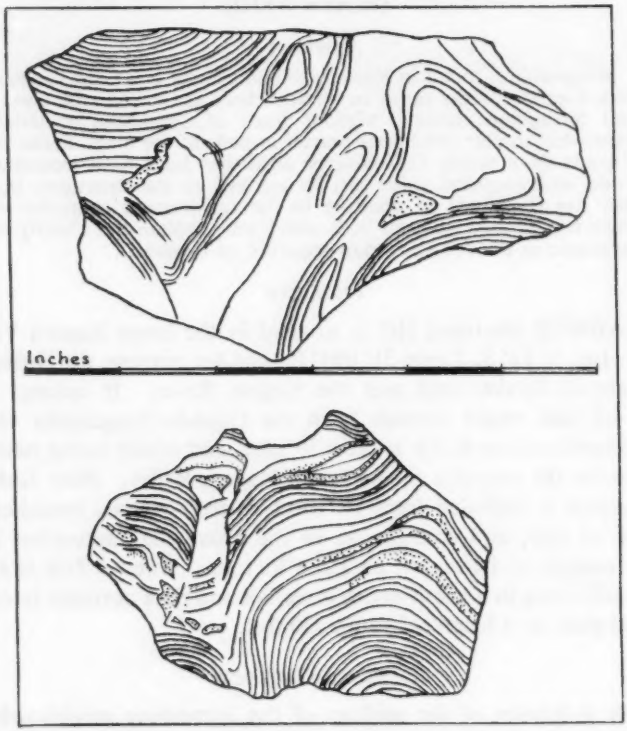
Little is known of the geology of the immediate neighbourhood. The rocks are believed to be Karagwe–Ankolean in age by general comparison of structure and lithology with those to the west mapped by Combe in Ankole and Bukoba (1932). The southern extension of the range of hills, to which Kabwer belongs is marked as Karagwe–Ankolean quartzite by Combe, and similar rock specimens to those occurring around Kabwer were collected by Combe near Rutunguru and on Kitara Ridge about five miles south of Kabwer. Rocks seen on the Nsongezi–Nyakanyasi road are typically phyllites and quartzites of the Karagwe–Ankolean System.

DESCRIPTION OF THE ALGAL BEDS

The north and north-east slopes of Kabwer Hill are composed of

[1] Published by permission of the Director, Geological Survey, Uganda.

cliffs, bluffs, and a coarse scree of a highly brecciated siliceous rock. Fragments of white quartzite, white, pink, or brown chert and glassy or milky, siliceous material are loosely but durably cemented by silica or ironstone. In places, large spheroidal blocks of very compact white and red-brown cherty material occur; elsewhere angular flinty masses



TEXT-FIG. 1.—Tracings taken from polished surfaces of stromatolites, ? *Collenia* cf. *undosa*, in cherty siltstone, Nsozinga Hill, Singo, Uganda. (Half natural size.)

are cemented together with open cavities which frequently contain clusters of quartz prisms. Many fragments display irregular banding. The bands are often arranged haphazard but occasionally show a concentric arrangement. In localized patches and especially near the summit of the hill ferruginous cement predominates, and banding in alternate iron-rich and iron-poor zones is common.

Bluffs of irregularly cemented, structureless cherty rock occur on the eastern side of the hill; various directions of fracture and re-cementation are apparent without any dominant direction.

Along the north–south crest of the hill and forming a zone extending

down the northern slope to the road, brecciation is less marked and concentric structures are very prominent. On the top of the hill these structures exhibit alternating, siliceous and ferruginous bands about ten to an inch, differential weathering of which has given rise to ovoid or cigar-shaped fragments or groups of individuals loosely cemented together. Some individuals are circular in cross-section with a long axis very many times greater than the diameter; other groups have a flat oval cross-section, which may be due to tectonical compression; others are almost spherical. All sizes are encountered from individuals of $1\frac{1}{2}$ to 8 inches in cross-section. It is the smaller sizes which show proportionately longer central axes.

On the northern nose of the hill, the zone can be followed into more flinty rock with less iron and consequently the concentric banding is less apparent at first sight, but closer examination reveals groups of fine concentric bands of alternating white and pink colour in the large spheroidal blocks of flinty siliceous rock. Occasionally the banding is undulating and abandons the concentric arrangement.

Owing to extensive fragmentation it is difficult to ascertain the original orientation of the concentric structures. They appear to form two or three lenses each about 100 feet long with an outcrop width of 20 feet striking at 170° azimuth and dipping steeply westward. The long axes of the structures appear to be sub-parallel and plunge steeply in the principal plane of the lenses.

There is no calcareous material to be detected in the algal beds, and under the microscope no organic structure could be recognized. The rock is made up of a fine mosaic of quartz grains.

From the description of the stromatolite beds three generalized types of algal structures may be recognized.

(1) Forms with fine, wavy and undulose laminations usually encountered in the more cherty beds and frequently severely fractured. These may be ascribed to *Collenia* cf. *undosa* Maslov.

(2) Isolated ovoid-shaped masses with concentric banding. Individuals attain a diameter of at least 8 inches. These are doubtfully ? *Oncolithes* Pia.

(3) Cylindrical or slightly turbinate forms, usually colonial but unbranched; 1–3 inches in cross-section and at least 6 inches in length; such forms clearly resemble *Collenia* cf. *ferrata* Maslov.

Discussion

Stromatolites and other algal forms are not uncommon in the Pre-Cambrian of Central and East Africa. They were first recognized by Salée (1931) in rocks of the Système de la Lumpungu of Urundi, and by Teale (1931) in the " Malagarazi Series " of Tanganyika. They were identified as *Cryptozoon* sp. Hall, by Schuster and Dietrich (1933).

Collenia sp. Walcott was described from rocks of the Bushimai System of Katanga by Cahen and Mortelmans (1941) and by Jamotte (1944) from the base of the Système des Mines. In 1946 Cahen, *et al.* reviewed the knowledge of Pre-Cambrian algae in the Belgian Congo and came to the conclusion that they were of some stratigraphical significance. What were considered to be primitive forms of *Collenia* are particularly abundant in the Lubudi Limestone of the Kibara System and the Sekelolo Limestone of the Haut–Shiloango System of the Lower Congo. The younger Systems of the Bushimai and the Schisto-dolomitique are characterized by a wider range of " species " of *Collenia* and especially by the typical forms of *Collenia ferrata* and *Conophyton* sp. Maslov and by micro-algae. Finally in the Kundelungu System micro-algae were found to the exclusion of other forms. More recently, however, Beugnies and Dumont (1954) have described stromatolitic limestone reefs in the Kakontwe Limestone of the lower Kundelungu System, thus extending the upper range of *Collenia.*

Macgregor (1940) described stromatolite structures in the Bulawayan System which closely resemble the more primitive forms of *Collenia.* Combe (1948) recorded possible algal forms in the Singo Series of Buganda, overlying the Karagwe–Ankolean System. Combe described the occurrence as follows: " On Nsozinga they (the siltstones) are usually light grey extremely fine-grained rocks varying from quartzite to cherty and from massive to thinly-banded. Of frequent occurrence are brecciated types and others in which the banding is crumpled. Peculiar ovoid concretions of banded cherty rocks are sometimes found. Of special interest is the occurrence of structures similar to those regarded as algal forms of the *Collenia* type." From an examination of Combe's specimens the forms approximate best to *Collenia* cf. *undosa.*

Considerable doubt has been expressed by Cloud (1942) as to the genetic significance of the morphological character of the various stromatolites. Variations in external form in algae may be brought about by crowding, rapidity of growth, agitation of the water, and sedimentation. He asserts that the use of terms such as " cryptozoon ", " collenia ", etc., should be purely descriptive without any genetic significance. More recently, however, Harlan Johnson (1952) summarizes certain algal characteristics and retains the genera *Collenia* and *Cryptozoon* and their species.

It appears, therefore, that at the present state of knowledge, Pre-Cambrian stromatolites are of uncertain stratigraphical value.[1] Their presence in the quartzite rocks of Tanganyika and Uganda is, however,

[1] Vasconcelos (1951) has shown, however, that the presence of stromatolites in the Système du Bembe of Angola has confirmed lithological correlations with rocks of the Katanga.

significant. *Silicification* and *brecciation* appear to be common phenomena associated with algal reefs. Jamotte (op. cit.) describes *Collenia* in the dolomitic limestone of the Série des Mines at Kasompi completely silicified and weathered out of their matrix. Vasconcelos (op. cit.) describes fossil algae in a completely silicified condition and his specimens figured by Mouta (1954) bear a striking resemblance to the concentric structures at Kabwer. Of particular interest is the description by Vasconcelos of a red, ferruginous rock presumed to have been a dolomite much altered and silicified and persistently displaying orbicular structures. Beugnies and Dumont (op. cit.) find the laminations of the stromatolites consisting of very pyritic limestone and fine detrital quartz. The algal beds of the Anti-Atlas described by Choubert (1952) in a number of papers have laminations or lenses of quartz and show varying stages of silicification. However, it is evident that *Collenia* and allied forms were lime-secreting and reef-building and their presence implies original calcareous horizons. The siliceous rocks of Kabwer Hill and to some extent those of Nsozinga Hill in Singo, Uganda, were originally calcareous and the silica is mainly secondary. Combe records in unpublished notes, banded pink-white chalcedony associated with cherty rocks and quartzitic sandstone with cavities on the south-south-east continuation of Kitara Ridge, which is in the same strike and presumably at about the same stratigraphical horizon as the Kabwer occurrences. He further states that these highly siliceous beds there pass laterally into normal shales, slates, and quartzites. "These peculiar rocks certainly seem to have been formed by the process of metasomatic replacement by hot siliceous solutions, but what the conditions were leading up to this replacement are not yet known." Deposition of silica as a replacement is considered by Twenhofel (1950) to take place in most cases directly from sea water before consolidation of calcareous sediments but replacement by ground water in consolidated rock is also a common occurrence.

In this connection the work of Sorotchinsky (1953) and Woodtli (1954) is worthy of note. By a combination of extensive petrographic work and chemical analysis they have demonstrated remarkable metasomatic changes in rocks of the Kibali System in Eastern Belgian Congo. Additional supporting evidence is provided by cores from a number of bore-holes drilled in the neighbourhood of the Kilo-Moto Mines. A wide variety of rocks, phyllites, quartzites, and albitites, are believed to have been produced by metasomatic alteration from an original calcareous rock type under the influence of a deep water-table. The series of changes range from an original limestone through a dolomite, frequently sideritic, to albitites, which in turn may be affected at levels nearer the surface by processes of amphibolitization, silicification, or phyllitization. Sorotchinsky casts doubt on the original

arenaceous character of some quartzites and in particular quotes cases of certain fossiliferous Palaeozoic beds of Belgium which show undoubted examples of wholesale silicification without affecting skeletal structures. He suggests, " Il doit suffire de quelques traces de composé soluble de la silice dans les eaux d'une nappe aquifère pour constituer, au bout de milliers d'années, une roche quartzeuse à la place d'un calcaire."

Although the zone of algal-like structure is less brecciated, it none the less has been very considerably fractured. Two possible causes may be suggested for the brecciation. It may represent original reef debris or secondly it may be the result of autobrecciation during silicification. Both processes were probably operative. From this point it is possible to speculate on the origin of certain zones of ferruginous cherty breccia which occur both in the Karagwe–Ankolean phyllites and in the Singo Series of Uganda. Apart from certain calcareous basal beds in the Karagwe–Ankolean the presence of which is being more widely recognized as a result of recent mapping, there is a remarkable scarcity of sedimentary limestones in the various groups of rocks of Uganda. The undoubted total silicification of these algal beds at Kabwer and Nsozinga may provide an explanation for the absence elsewhere of calcareous horizons; brecciated cherty and ferruginous zones may bear witness to replaced dolomites or limestones.

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FIG. 1.

FIG. 2.

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GEOLOGICAL SURVEY,
ENTEBBE,
UGANDA.

EXPLANATION OF PLATE XXIII

FIG. 1.—? *Oncolithes* Pia, completely silicified and weathered out from matrix, Kabwer Hill, Tanganyika Territory.

FIG. 2.—Large detached block of cherty quartzite composed of a compact mass of stromatolites, ? *Oncolithes* sp., Kabwer Hill, Tanganyika Territory. (The rule is marked in inches.)

The Problem of Facies Changes and Sliding, South of Loch Leven, Argyllshire

By W. G. Hardie

Abstract

All the bedded rocks outcropping within the fault-intrusion of Glencoe, south and west of Garbh Bheinn summit (2,835 feet, Text-fig. 1), are shown to be exotic. They probably represent down-stoped fragments of the now eroded roof of the intrusion. This change of interpretation completely invalidates the theory of rapid facies changes, proposed by the writer in 1952. New evidence relating to the remarkable thickness variation of the Binnein Quartzite on the eastern side of the Garbh Bheinn downfold is also discussed.

In my paper on the Lochaber Series (Hardie, 1952) I concluded that a rapid sedimentary transition takes place between the Eilde Quartzite and Eilde Schist on the eastern side of the Garbh Bheinn downfold. This theory must now be abandoned, since it is based upon two assumptions, which will now be shown to be invalid.

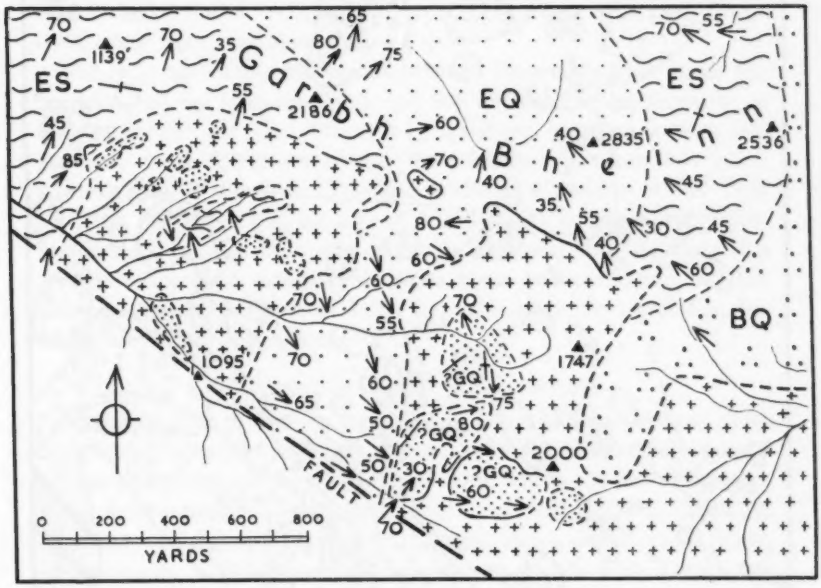
Area South of Garbh Bheinn Summit

Four Main Exotic Outcrops.—Four main outcrops of bedded rocks, largely consisting of quartzite, are now believed to be present within the fault-intrusion south of Garbh Bhein summit (2,835 feet, Text-fig. 1). Formerly, only a single outcrop, mapped as Eilde Schist, was recognized (Bailey, 1934, fig. 4, p. 487; 1 in. Geological Survey map, Sheet 53, Third Edition). This outcrop roughly corresponds to the one shown in Text-fig. 1 as lying to the south-west of spot height 2,000. Later the greater part of it was correlated with the Eilde Quartzite, lying to the north, while to the east a small isolated outcrop of quartzite, believed to be Binnein Quartzite, was recognized (Hardie, 1952, Text-fig. 1, p. 274). Further study has since led to the mapping of two additional outcrops of bedded rocks within the fault-intrusion, west and north of the previously mapped ones, as well as to the conclusion that all the rocks are exotic.

Recognition of the south-western outcrop of bedded rocks (Text-fig. 1), has been necessitated by a local alteration in the mapped position of the western contact of the fault-intrusion (Text-fig. 2). Previously the western half of this quartzite outcrop was mapped as lying outside the fault-intrusion and forming part of the Eilde Quartzite, while the eastern half was shown as part of the bedded outcrop to the east (Bailey, 1934, fig. 4, p. 487; Hardie, 1952, text-fig. 1, p. 274). I am now convinced, however, that the local western limit of the fault-intrusion lies further west than hitherto believed, and that the small amounts of fault-intrusion shown in the three exposures marked A, B, and C in Text-fig. 2 are parts of a continuous narrow tongue which

isolates an area of quartzite to the east from undoubted country rock to the west. The contacts of the fault-intrusion seen in these three exposures are steep as in the case of the undoubted contacts further north.

The lithology (details later) and regional structure of the quartzite on either side of this postulated tongue of fault-intrusion is different. To the west the strike is constant, whereas to the east it is variable. The most probable explanation of this is that two quartzites are present,

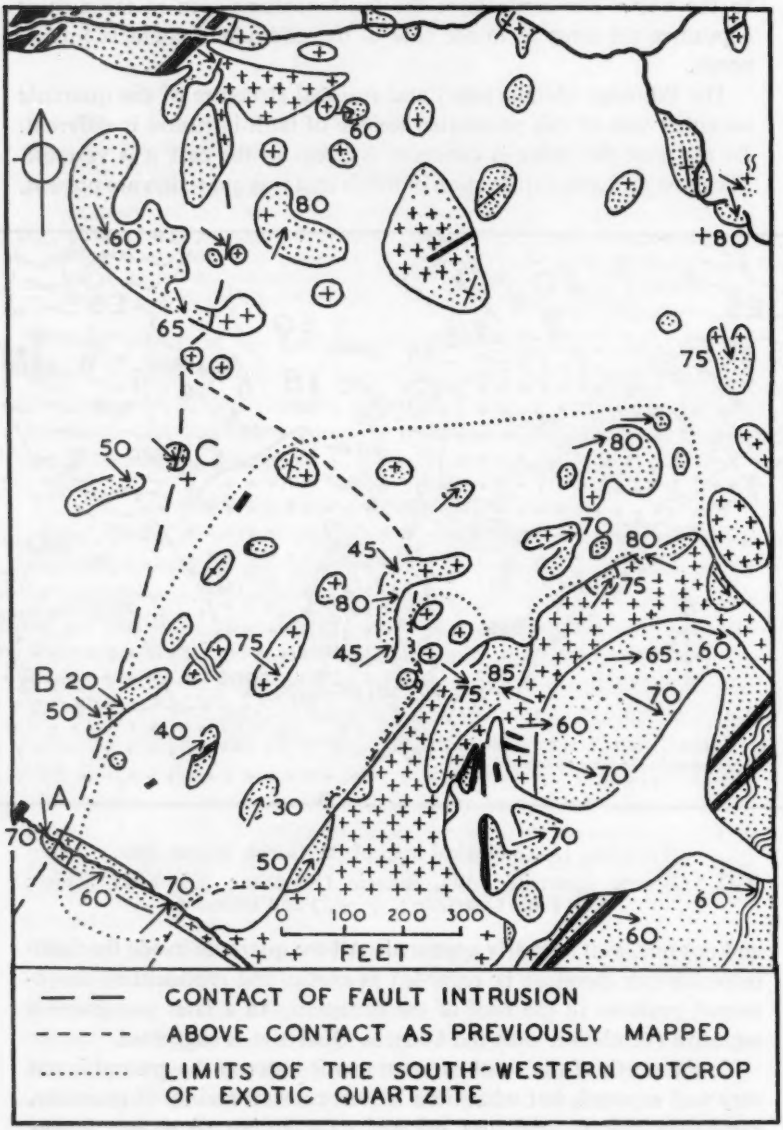


TEXT-FIG. 1.—Geological map of the Garbh Bheinn area.
?GQ, ? Glencoe Quartzite; BQ, Binnein Quartzite; ES, Eilde Schist; EQ, Eilde Quartzite; + +, Fault intrusion.

and not one, as it formerly appeared. All the quartzite inside the fault-intrusion can therefore be regarded as exotic, and representing down-stoped portions of the roof of the intrusion. In a later paragraph a tentative correlation with the Glencoe Quartzite is suggested.

To the north of the south-western exotic outcrop the ground is not very well exposed, but what little is seen consists mainly of quartzite. Previously this ground was mapped as fault-intrusion, but I now suggest that it is probably best to regard it as the site of yet another mass of exotic quartzite intruded in places by the fault-intrusion.

The conclusions just reached invalidate my previous arguments against sliding on the eastern side of Garbh Bheinn, which were based



TEXT-FIG. 2.—Exposure map of part of the fault-intrusion south of Garbh Bheinn. Crosses represent fault-intrusion; dots, quartzite; wavy lines, schist; full black, dykes.

upon the belief that the bedded rocks lying within the fault-intrusion were in situ (Hardie, 1952, pp. 280–1; 1953, p. 115).

Lithology.—A characteristic feature of the bedded rocks forming the exotic outcrops is an interbedding of relatively pure feldspathic quartzite with quartzose beds containing very variable amounts of mica. The quartz-rich beds are generally more massive than the less pure beds, and are frequently several feet thick. Occasional beds of hornfelsed schist are also interbedded with the quartzite; but with the exception of the narrow strip of ground formerly mapped by me as Eilde Schist (Hardie, 1952, text-fig. 1, p. 274), where beds several feet thick occur, these are almost always thin.

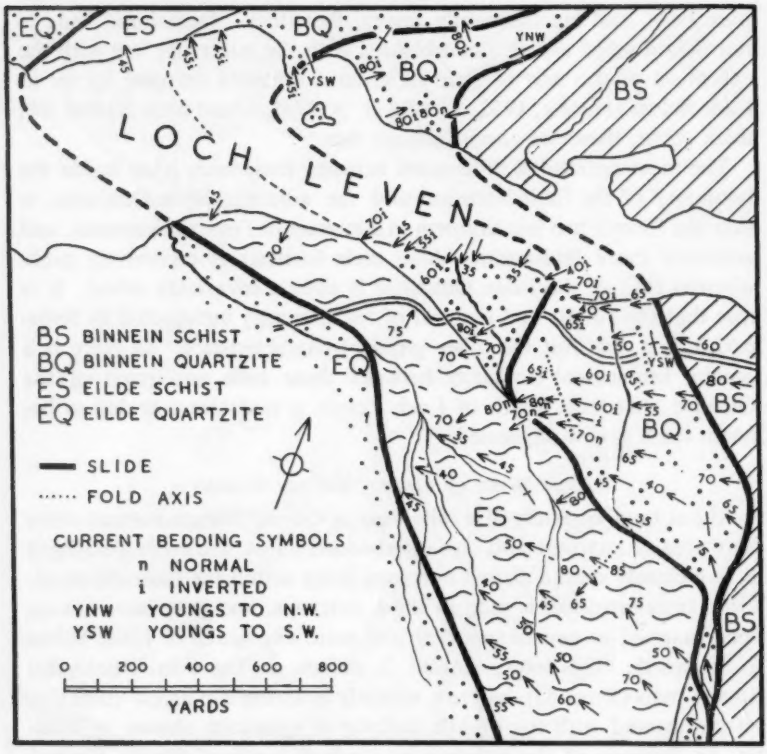
The most noticeable differences between these beds lying inside the boundary of the fault-intrusion and the adjacent Eilde Quartzite, is that the former are less uniform in composition, more micaceous, and generally more feldspathic. Also their feldspar is commonly pink, whereas that of the Eilde Quartzite is almost invariably white. It is true that the colour and amount of feldspar may be affected by feldspathization, but not the other physical characteristics. As there is a general lithological similarity between these beds and parts of the Glencoe Quartzite, south of Loch Leven, a tentative correlation between them is now suggested.

Area West of Garbh Bheinn Summit

About three-quarters of a mile west of Garbh Bheinn summit there is an area of quartzite and rare interbedded schist, shown in Text-fig. 1 as five closely spaced dotted outcrops lying within the fault-intrusion. Little fault-intrusion is seen in these outcrops, and they have always been mapped as continuous with the main exposures of Eilde Schist to the north. This interpretation is shown on the 1 in. Geological Survey map (Sheet 53), where a westerly pointing dip arrow coincides on the ground with the middle outcrop of quartzite shown in Text-fig. 1. Because of the conclusions reached south of Garbh Bheinn, however, it would now appear more probable that this quartzite should be interpreted as exotic masses lying within the fault-intrusion. This, of course, involves drawing the contact of the intrusion through the unexposed ground between the quartzite and Eilde Schist. If this is the correct interpretation, it then follows that the quartzite can no longer be regarded as representing the final stage of a rapid local sedimentary transition in the Eilde Schist (Hardie, 1952, p. 277).

The inclusion of the quartzite within the fault-intrusion is entirely reasonable, since this latter where exposed abounds in such masses, varying from a few inches to many yards across. Three of the largest of these masses, all regarded as exotic, are shown in Text-fig. 1, to the south-east of a large enclosure of schist. The latter is regarded as a roof

pendant of Eilde Schist, rather than an exotic mass of unknown age, since a probable former connection with the main outcrop extending in an approximately north-easterly direction, across ground now occupied by the fault-intrusion, is suggested by the almost exclusive presence of schist amongst the very variable-sized inclusions.



TEXT-FIG. 3.—Geological map of the Loch Leven district north of Garbh Bheinn. Geology north of Loch Leven after E. B. Bailey (1934, fig. 3).

The eight outcrops of quartzite just considered agree broadly in lithology with the Glencoe Quartzite, and a tentative correlation is suggested. Admittedly the quartzite here shows a greater lithological range than south of Garbh Bheinn, but no more than is found in the Glencoe Quartzite south of Loch Leven.

SLIDES

All the most important evidence cited by me in 1952, in support of the theory that there is a major unexposed sedimentary transition

between the Eilde Quartzite and Eilde Schist on the eastern side of the Garbh Bheinn downfold, has now been shown to be either inapplicable or else erroneous, and consequently this theory must be abandoned. Such a conclusion fully justifies Sir Edward Bailey's suspicion of this theory (Bailey, 1953, pp. 111–12). According to me a change of facies more satisfactorily accounted for the rapid variations in thickness shown by the above beds on the two sides of the Garbh Bheinn downfold than did Sir Edward Bailey's tectonic theory involving sliding. I am now happy to say that I am in complete agreement with Sir Edward that the observed thinning of the beds is very probably of tectonic origin (Bailey, 1934, p. 485).

I should now like to suggest that the markedly diachronic part of the junction between the Binnein Quartzite and Eilde Schist on the eastern side of the Garbh Bheinn downfold, which I described for the first time in 1952 and ascribed to an unconformity (Hardie, 1952, p. 282), is most probably a slide. The probable course of this slide is shown in Text-fig. 3, partly in Binnein Quartzite, partly along its western margin. Eventually, southwards, it probably coincides with the junction between the Binnein Quartzite and Binnein Schist, which Sir Edward Bailey (1934, pp. 489–91) has shown to be a slide. This newly mapped slide is very probably a southerly continuation of a minor slide mapped by Sir Edward Bailey (1934, p. 491, footnote; fig. 3, east), as occurring within the Binnein Quartzite north of Loch Leven only.

A recent study of the many examples of current bedding in the Binnein Quartzite has provided further evidence for the existence of this newly mapped slide. As shown in Text-fig. 3, the beds do not always young in the same direction; this has been interpreted as due to folding. It is particularly interesting to notice that along part of the course of the slide, immediately south of the road, Binnein Quartzite is seen to young towards the older Eilde Schist. Presumably the return limb of quartzite has been replaced by the slide.

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GEOLOGICAL DEPARTMENT,
BIRMINGHAM UNIVERSITY.

CORRESPONDENCE

AGE OF THE WEALDEN IN NORTH-WESTERN EUROPE

SIR,—I was interested to read (*Geol. Mag.*, xcii, 430–431) Dr. F. W. Anderson's agreement with my main conclusions on the correlation of the English and German Purbeck—Wealden.

His confirmation that Wolburg's correlation of the top Weald Clay of Sussex with the German Wealden 4 zone is incorrect is particularly valuable ; so is his palaeontological explanation of how the mistake came about. My argument (p. 276) was, of course, based mainly on general geological considerations, and it is satisfactory to learn that re-examination of the Berwick ostracods leads to the same conclusion.

Regarding the rest of the succession, Anderson's proposed correlation (unsupported by any new facts) is broadly similar to my own. We appear to differ in the amount of " Wealden 3 " ascribed to Hastings times and in the age of the top of the Hastings Beds. Unfortunately no published work exists on which these and related issues might be settled, and discussion at such a level of precision must remain sterile until it does. That is why my boundaries (Text-fig. 2) are left vague.

Concerning the wider subject of the N.W. European Wealden as a whole, Anderson states (incorrectly, in my view) that " very little of the relevant palaeontology has been published " and that the conclusions " must in many instances remain highly speculative ". Large gaps do indeed exist in the ostracod palaeontology of England. But, from what he says next, it is clear that Anderson himself is in a good position to remedy this. A major point of my paper, however, was to restate the old dictum (also disinterred by Hughes (*Geol. Mag.*, xcii, 201)) that all the evidence should be used : molluscs, plants, petrology, as well as the ostracods.

Anderson also raises the fascinating subject of the Cinder Bed. I had already indicated (pp. 269 and 276) that this corresponds approximately with the base of German " Wealden 1 ". It is certainly an important horizon, probably occurring over a great part of the Anglo-Paris basin, and perhaps extending to the Alps.

Since the work under discussion went to press, a new contribution has come to hand which adds further weight to my proposed correlation of Wealden 4 with the Lower Berriasian. Bartenstein and Burri now report (1955, *Ecolog. géol. Helv.*, xlvii, 426) *Protocythere propria emslandensis* n. subsp. from both of these formations. Incidentally, these are the oldest known occurrences of that genus.

The critical ostracod and other faunas referred to in my paper may be consulted in this Department.

P. ALLEN.

DEPARTMENT OF GEOLOGY,
UNIVERSITY,
READING.

27th October, 1955.

REVIEWS

PREHISTORY AND PLEISTOCENE GEOLOGY IN CYRENAICAN LIBYA. By C. B. M. MCBURNEY and R. W. HEY. Occasional Publications of the Cambridge University Museum of Archaeology and Ethnology, IV. Quarto, pp. xii + 308, 16 pls., 40 figs. Cambridge Univ. Press, 1955. Price £3.

This admirable report of two seasons' fieldwork in the Gebel Akhdar hills and along the coast, and the important conclusions arrived at, results from intimate collaboration between geologist and archaeologist. In the first half of the book Dr. R. W. Hey deals with the Pleistocene geology in 9 chapters, under the headings "Shorelines and Marine deposits" and "Continental deposits". Six, perhaps seven, raised shorelines are indentified, some of them carrying patches of marine deposits. The heights range from 6 m. to 200 m. and they interpreted as of eustatic origin and indicating prolonged tectonic stability. "It is therefore concluded that the Déperet-Lamothe theory, whatever the faults of the means by which it was arrived at, may well be substantially correct."

The continental deposits, some containing various types of Palaeolithic implements, comprise consolidated dunes, some of which run down below present sea-level and must have been formed at a time of regression, a sheet of "younger gravels", and tufas. The mutual relations of these deposits, their climatic significance, and their relations to the shorelines, are discussed step by step with great care and lucidity. The sequence-dating and tentative wider correlations are the more convincing for the inductive and logical reasoning by which they are arrived at, and the objective manner in which they are stated. The implications are of wide importance for the tectonic, eustatic, and climatic history of Pleistocene times.

In the second half of the book Dr. C. B. M. McBurney describes the Palaeolithic and Neolithic industries of the region and the excavation of a cave, and discusses the integration of the industries with the geology and with Pleistocene chronology in general. Appendices by Dr. Hey on the mollusca and on plant-remains from the tufas, by the late Dorothea Bate on the vertebrates and by other experts on cave deposits, pottery and charcoal, conclude a book on which all concerned are to be congratulated.

W. J. A.

MINERALS IN WORLD INDUSTRY. By W. H. VOSKUIL, Chief Mineral Economist, Illinois Geological Survey. McGraw Hill Book Co., 1955. pp. vii + 324, with 26 figs. and 38 tables. Price 43*s*.

Books presenting mineral statistics are in general dull, but these 300 pages telling "which countries produce which minerals, how much of each, what the value is, who sells and who buys in the world's markets and how the minerals are used" is fascinating not to say exciting for geologists who have interests in commerce and industry or in the affairs of the world. This book should be as useful to directors of geological study who are called upon to advise students and research workers in the choice of their careers as it is valuable to metallurgists and chemical technologists or for prospective dealers on the stock exchange and economists for whom it may well have been prepared. Largely a digest of American government and other official publications, it presents a balanced picture of mineral exploitation in most of the countries on an uniform scale with note of quantitative and qualitative limitations as imposed by costs and the requirements of the consuming industries. It is essentially a source book for economic geographers, but although the locations of mineral sources are demarked as situate within political boundaries rather than related to the matrix formations, the geological background of description is evident and in general sound.

Most of the specific and quantitative information has appeared elsewhere in official records. The compilations were begun as the United States of America was recognizing the mineral insufficiencies of the Western Continent, and for military emergencies took to the stock-piling of "strategic minerals".

It has been usual to regard as the key minerals of industry and commerce those the lack of a few tons of which could hold up the manufacture of large quantities of products essential for the maintenance of the national economy. In this book Professor Voskuil has changed this emphasis, and surveying the world holds that the real key mineral of western civilization is coking coal, of prime importance only where it is available in such adequate quantity that with iron ore cheaply accessible to its region the coke made from it can support enough blast furnaces to supply with pig iron the great nations' steel industries on which all transport, manufacturing and ancillary machinery essentially depends. The coalfields with coking coals about the Mississippi valley hold the keys of major concentration of industries of the United States. Their blast furnaces produce 45 per cent of the world's pig iron, a quantity which is barely equalled by the summation of what is made in the Rhineland-Ruhr 20 per cent, Russia 15 per cent, and Britain just short of 10 per cent, with remainder contributed by all the other countries also about 10 per cent, and with only undeveloped Manchuria having coking coal in sight in quantity sufficient to promise future development of an iron and steel industry on a comparable continental scale.

The first third of the book is taken up with a review of the raw materials for the world's steel industries with adequate assessment of known supplies and prospects of iron ores, coal in its several varieties and rank, and of the diverse alloying elements which, with iron, make up steel. There is special regard to foreign ores which have to be imported by America. Similarly informative and up to date are following chapters dealing with the distribution of oilfields, their recognized resources, and their production of petroleum and gas, with a short appreciation of the importance of water power and of nuclear energy to be developed from uranium. The base metals copper, lead, and zinc, and the light metals aluminium and magnesium, are considered in world perspective, and good information is provided about their place in American industry. Welcome to geologists are the later chapters on the mineral plant foods, nitrogen, phosphorus, and potash, and the notes on sulphur and numerous other mineral substances and rocks supplied in larger or smaller quantity to chemical manufacturers. The final chapter is a fair presentation of the American outlook and policy in relation to minerals in undeveloped countries and in world affairs.

W. G. F.

INTRODUCTION TO PHYSICAL GEOLOGY. By CHESTER R. LONGWELL and RICHARD FOSTER FLINT. vii + 432 pp., 340 figs. Chapman and Hall, London, 1955. Price 40*s*.

The authors have reinforced their own experience in teaching Physical Geology by consultation with over 140 American College departments before writing this book. According to the preface they aim at a " streamlined textbook, reasonably complete for an introductory course but concise, clear, and economical ", produced at minimum cost. In general the book conforms to this rather exacting standard, covering the wide field of the subject in a balanced and lucid manner while keeping the cost within the reach of the average British student.

Introductory chapters, including a full treatment of geological time, are followed by Igneous Geology and Weathering and Soils. Thereafter the various agents and processes of denudation are dealt with systematically, with the inclusion of a chapter on Ground Water, and lead logically to an account of the Sedimentary Rocks. The final chapters deal with the Deformation of the Earth's Crust; Metamorphism, Earthquakes, and the Earth's Interior; Mountains and Geosynclines; Geology and Industry. Four appendices concern themselves with the identification of common rocks and minerals, maps, and a summary of symbols and conversion tables. The abundant illustrations are uniformly good. The general excellence of the work emphasizes an occasional weak point (the sketchy and cryptic section on movement of rock particles by wind, for example), but this up-to-date, well designed, clearly written book should have a wide appeal.

PHYSICAL GEOLOGY. By L. DON LEET and SHELDON JUDSON. ix + 466 pp., 361 figs. Prentice Hall, New York, 1954. Price 70*s*.

This is another excellent but more obviously transatlantic textbook. In Britain it is handicapped at the outset by its price, which is too high for many of the students for whom it is intended. Written primarily for beginners, it combines an elementary approach with a treatment rather more detailed than is normally found in books of this type. This, together with the inclusion of much recent work and the clear, incisive style in which it is written, should give the book an immediate appeal to the more enthusiastic student. It should certainly be read by all who teach Physical Geology.

GEOLOGY, PRINCIPLES AND PROCESSES. By WILLIAM H. EMMONS, GEORGE A. THIEL, CLINTON R. STAUFFER, and IRA S. ALLISON. vi + 638 pp., 519 figs. Fourth edition, McGraw Hill, 1955. Price 49*s*.

The fourth edition of this comprehensive text on Physical Geology has been completely revised with the addition of new data and concepts.

INTRODUCTION TO GEOLOGY. By O. D. VON ENGELN and KENNETH E. GASTER. ix + 730 pp., 373 figs. McGraw Hill, 1952. Price 59*s*. 6*d*.

GENERAL PRINCIPLES OF GEOLOGY. By J. F. KIRKALDY. 327 pp., 6 plates, 78 figs. Hutchinsons, 1954. Price 25*s*.

Each of these books contains a general introduction to Geology which includes some Palaeontology and Stratigraphy. The first devotes 301 pages to a survey of the stratigraphical column and its fossils with particular reference to North America in addition to a lengthy treatment of Physical Geology.

The second, modest in size and wide in scope, includes Physical Geology, Crystallography, and Mineralogy (in some detail), Petrology (with an introduction to the use of the Petrological microscope), Historical Geology (with a chapter on Fossils), Economic Geology and the interpretation of geological maps. The result, inevitably, is lacking in balance but provides a very clearly and attractively written introduction to the subject, mostly at a very elementary level.

W. W. B.

PUBLICATIONS RECEIVED

Geological Survey of Gt. Britain. The Geology of the Country between Burton upon Trent, Rugeley, and Uttoxeter (1 in. Geol. Sheet 140, New Series). By I. P. STEVENSON and G. H. MITCHELL, with contributions by C. J. STUBBLEFIELD, M. A. CALVER, K. C. DUNHAM, and W. BULLERWELL. pp. vii + 178, with 19 text-figs. and 9 pls. London, H.M.S.O., 1955, price 21*s*.

Bulletin of the Geological Survey of Gt. Britain, No. 9. Papers by G. A. KELLAWAY and F. B. A. WELCH, J. R. EARP and D. MAGRAW, E. G. POOLE and A. J. WHITEMAN, J. G. D. SMART, C. O. HARVEY, and A. D. WILSON. pp. iv + 58, with 8 text-figs. and 3 pls. London, H.M.S.O., 1955. Price 6*s*.

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K. Jinghwa Hsu. Granulites and Mylonite [illegible] and San Antonio Canyons, San Gabri[illegible] sity of California Press. 1955. pp. 2 [illegible] plate overlays in folder. Price $2.50.

Micropaleontology. Volumes 1 and 2—J[illegible] B. F. Ellis and A. R. Messina. pp. [illegible] plates. Price $5.00 per year and $2.0[illegible]

Proceedings of the Conference on Latin-A[illegible] 1954. Editor F. M. Bullard. The U[illegible] with text-figs. and map in folder. [illegible] Geology of Mexico, Metallic Ore Res[illegible] of Brazil, Geological Development of[illegible]

G. W. Himus and G. S. Sweeting. *The Ele[illegible]* Tutorial Press, Ltd. 1955. Second [illegible] and 2 pls. Price 14*s.*

W. H. Emmons, G. A. Thiel, C. R. Staufe[illegible] *Principles and Processes.* McGraw Hil[illegible] pp. 638 + 519 figs. Price 49*s.*

G. D. Hobson. *Some Fundamentals of Pe[illegible]* sity Press, 1954. pp. 139 + 41 text-fi[illegible]

A. I. Levorsen. *Geology of Petroleum.* [illegible] Francisco, 1954. (Bailey Bros. and S[illegible] 327 illustrations and 47 tables. Price [illegible]

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L. Cahen. *Géologie du Congo Belge.* H. Vaillant-Carmanne (Liège), 1954. pp. xiii + 577 (4to), with 98 text-figs. and 36 photographs.

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